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Wild Rice—*Indian Food and a Modern Delicacy*

Once an important food for many Indian tribes in the Northwest Territory, wild rice is still used by the remaining Chippewas, and more than one million pounds of it are gathered annually in Manitoba and Minnesota as a commercial enterprise for modern culinary use in Canada and the United States.

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Introduction

When the first explorers, missionaries and fur traders penetrated into the great Northwest Territory they found, growing in the abundant lakes, ponds and sluggish streams of the northern part of that area, a type of aquatic grain which was quite new to them and which proved to be the staple food of a large part of the native population in that region. The writings of those early adventurers are filled with glowing references to this spontaneous crop which required no plowing or sowing, and which each year, except when some misfortune befell, provided an abundant harvest of nourishing and palatable grain which sustained the natives through the harsh northern winter.

English explorers, perhaps because of its aquatic habit, named this remarkable plant " wild rice " or " Indian rice "; the French saw a greater resemblance to oats and called it " folle avoine " (wild or mad oat). Both were in agreement as to the importance of the crop in the nutritional economy of the people who possessed it, and both were lavish in their praise of it as an available and desirable source of food for white men in a region where lack of transportation made it necessary for them to live upon the resources of the country.

This untamed grain, which long ago caused Indian and white-man alike to smack their lips in delight, is still recognized as a fine delicacy, and even today the annual wild rice harvest is a matter of considerable, though local, importance. The wild duck, too, considers the ripened grains of this rice a perfect feast, and each autumn flocks in great numbers to the marshes to feed upon it.

A discussion of wild rice as an economic plant involves two main features: *a*) use of it as a food by the Indian and by the white inhabitants of North America, both historically and at the present time; *b*) the importance of it as a natural food for game birds and the part which it plays in wildlife conservation.

Much has been written about wild rice, but there appears to be no modern treatment which deals with all aspects of the subject, each author concerning himself only with that phase of the subject which most interested him. There is likewise no up-to-date treatment of the present importance of wild rice and the modern improvements upon the ancient methods of handling it. The particular purpose of this paper is to bring together pertinent information on all aspects of the subject as obtained from a survey of the literature and, wherever possible, to bring the treatment up to date by addition of material obtained from individuals and organizations directly concerned with wild rice in one or more of its various uses.

Botanical Aspects

Taxonomy. A list of 60 popular names for wild rice, drawn from both the French and English languages as well as from various aboriginal tongues, has been prepared by A. E. Jenks (24) in his extensive study of the plant as a food of the North American Indians. This list undoubtedly is incomplete. Most of the names have been local in nature, but among the more commonly employed the following have enjoyed at least reasonably widespread usage: wild rice, Canadian rice, American rice, Indian rice, squaw rice, wild oats, false oats, folle avoine, blackbird oats, water oats, Tuscarora, Manomin (Ojibwa) and Psin (Dakota). Scientifically, the plant which produces this valuable grain is *Zizania aquatica* L., but the multiplicity of synonyms and the wide differences among the various treatments of the genus make a consideration of the scientific nomenclature almost as formidable as a study of vernacular names. In this taxonomic treatment only the outstanding points are considered.

The genus *Zizania* was apparently first recognized by Gronovius, and was described and figured by him in his Flora Virginica. Linnaeus later adopted the generic name and in 1753 described the type species, *Z. aquatica*. Prior to 1908 this one species of *Zizania* was commonly accepted in North America, although in 1906 Hitchcock (19a) set off a small northern type as var. *angustifolia*. In 1908 this same worker used the name *Z. aquatica* L. for this small northern form and applied the name *Z. palustris* L. to the larger southern form, stating that this was the original treatment by Linnaeus. It now appears that this last contention was incorrect. The original species, *Z. aquatica*, was the large southern form, and the second Linnaean species, *Z. palustris*, established after examination of more material, was the smaller northern type.

In a 1924 revision of the genus, Fassett (14), placing considerable emphasis on the previously overlooked feature of pistillate lemma texture, reached the conclusion that there is only one good species represented by this complex. The differences between the northern and southern forms in themselves are great enough to merit specific distinction, but the occurrence of a mid-western intermediate form makes this inadvisable. He accordingly calls the one species *Z. aquatica* L. and recognizes three varieties under it.

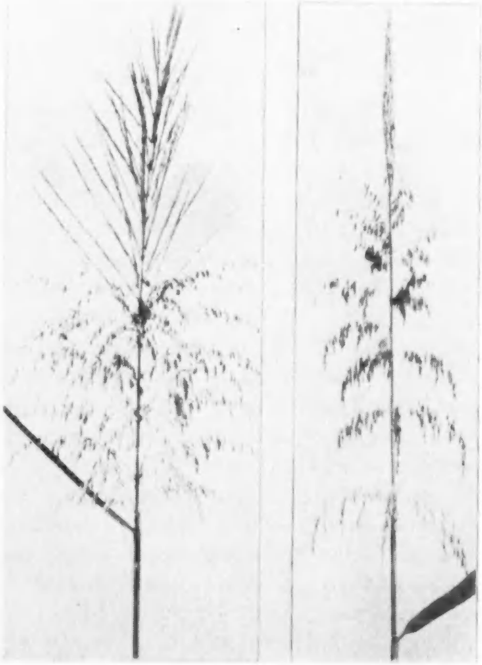

FIG. 1. Panicles of wild rice. Left, Potomac rice; right, Minnesota rice. (*From U. S. Dept. Agr., Bur. Plant Ind., Bull. 50*).

Zizania aquatica is an annual monoecious grass which attains a height of two to three meters and bears four to six leaves which are one to five cm. in width and up to 65 cm. long. The leaf sheath clasps the stem, and its edges, which are often streaked with blue, overlap so that the stalk is completely covered from the

node where the leaf arises almost to the node above. In the leaf blade the midrib is often a little nearer to one margin than to the other. The base of the stem is of a peculiar curved shape; and, since only one root is produced upon germination, the later roots arise from the first few nodes of the shoot. The root system is fibrous and spreading. The stem itself is hollow but is divided at the nodes by transverse septae, and at various intervals in the internodes by other diaphragms, called "pseudonodes". These partitions serve a useful function in dividing the stem into water-tight compartments so that the plant will float, even if part of the stem is injured. This is significant, since the plant often relies largely for its support, not upon the roots but upon the water in which it stands. Branching sometimes occurs, particularly in isolated plants and usually at the first or second node. Occasionally a cluster of stalks is produced by repeated branching. The terminal panicle is 20 to 25 centimeters in length, the lower staminate branches spreading, the upper pistillate branches less spreading. The glumes are obsolete, represented in the pistillate spikelet only by minute cupules. In the female floret, the palea and lemma enclose a small ovary which is topped by a dichotomous much branched stigma. The lemma itself is thin, papery, dull, finely striate and scabrous all over, with an awn two to seven cm. long. The cylindrical caryopsis is approximately 20 mm. long and one and five-tenths mm. wide, and is black. In the staminate spikelet the palea and lemma are sub-equal, and they enclose six yellow stamens.

Z. *aquatica* occurs near river mouths, above brackish water, along the Atlantic coast of North America from southern Maine to central Florida and along the Gulf coast into Louisiana. It is found inland in northern New York and rarely as far as Michigan.

Z. *aquatica* var. *angustifolia* Hitchc. differs from the preceding in the texture of the pistillate lemmas which are firm and tough with a lustrous coarsely corrugate surface, and are scabrous on the margins, along the awn and on the nerves, otherwise being glabrous; and in the size of the plant which is but 0.7 to 1.5 m. tall with leaves only four to ten mm. broad and a panicle considerably shorter than in the preceding variety. The caryopsis is about 13.5 mm. long and two mm. broad, but sometimes reaches 18 mm. in length. This variety occurs from eastern New Brunswick and northern New England westward into central New York and eastern Ontario. It occurs locally farther west and south to northern Indiana.

In the region from Lake Michigan to North Dakota, southward to Nebraska and locally as far south as eastern Texas, Fassett recognizes another variety, Z. *aquatica* var. *interior* Fassett. In this the pistillate lemmas are of the same texture as in var. *angustifolia*, but the stature of the plant approaches that of the coastal form, reaching a height of 0.9 to three m. with leaves one to three cm. in width and 40 cm. long. The caryopsis is of about the same size as that of var. *angustifolia* or possibly a little longer. There is some evidence in New Brunswick (50) that the varieties *angustifolia* and *interior* may not be distinct.

On the tidal flats of the St. Lawrence River near Quebec, in a rather restricted area, Fassett discovered a form of Z. *aquatica* which he called Z. *aquatica* var. *brevis* Fassett. The culms were only two to six and five-tenths dm. in height and the leaves were three to nine mm. wide. In lemma texture this form approached the coastal type, but the pistillate awn was short. A type of this sort had previously (1920) been referred to in a consideration of wild rice in Canada (18). Although all these varieties are recognized in the new edition of Gray's

Manual, the second edition of Hitchcock (20) omits var. *brevis*.

In addition to the taxonomic varieties of wild rice, there are, at least in Minnesota (36), distinct strains which differ notably in the number of kernels per head, the average size of the kernels and the date of ripening. These features are fairly constant from year to year within given stands. Several of the large-kerneled strains constitute the " giant wild rice " which has been so highly praised by the aquatic nursery men who sell it to be planted as a game food.

FIG. 2. Wild rice on Lac du Bois, Manitoba, Aug. 1, 1949, when it was in flower. (*Photo by H. B. Williams*).

Silveus (48) and Hitchcock (20) have both recognized a second North American species of *Zizania*, the perennial *Z. texana* Hitchc. from south-central Texas. A third species of the genus, *Z. latifolia* Turcz., the Manchurian water rice, is widely cultivated in China, not as a grain but as a vegetable. A fungus, *Ustilago esculenta* P. Henn., infects the basal portion of the stem, causing it to form a tender and succulent enlargement which is much relished.

In this discussion consideration of wild rice as an economic plant will be limited to *Z. aquatica*. Moreover, no attempt will be made here to consider the relative economic importance of the several varieties, since no reliable information of this sort is available.

Ecological Requirements. Wild rice has usually been regarded as a plant of extremely implastic requirements, but recent investigations indicate that it may have a greater tolerance than has thus far been suspected. The ideal conditions for its growth are found in shallow lakes and ponds, and along the borders of sluggish streams where the bottom is of mud to a depth of five or six inches, although occasionally it can be found on a sandy bottom. Although spreading, the root system is shallow, and thus the mud need not be of great depth and the nature of the underlying soil is of little importance.

The depth of the water in which it grows may range from six inches to three and one-half feet, and in rare cases down to seven feet, but must be fairly constant. It is interesting to note that wild rice seldom grows in bodies of water where there is more than a three-foot rise of water level in the spring or early summer which is prolonged for any great length of time, the periodic failure of the crop in certain rice beds of the upper Mississippi Valley being ascribed to the common occurrence of high and pro-

longed spring freshets. Data collected over a period of years in several Minnesota lakes have demonstrated that a water stage 12 or more inches above normal level during the period May 15 to July 1 caused failure, and a six-inch excess reduced the crop to one half. In Minnesota, according to J. B. Moyle (36), the best crops are harvested in years of "sub-normal rainfall and receding water levels". On the other hand, the plant thrives in tidewater rivers where there is a daily rise and fall of the water level up to three feet, sometimes even leaving the beds completely exposed at the ebb. Yet even here it will not stand prolonged elevation of the water. If the level drops appreciably, moreover, and remains so, the rice beds tend to become infested with cattails and coarse grasses which choke out the rice. Whether there are any differences of tolerance to water conditions among the various taxonomic varieties is not known.

In 1904 (46) a worker from the Bureau of Plant Industry discovered a cluster of wild rice plants growing near Washington, D. C., entirely above the tidal zone in some mud which the year before had been pumped out of the Potomac and had no doubt contained the seed at that time. The earth was so firm that a two-horse mowing machine was driven over it to cut away the growth around the clump. This suggests that there is some variation in the requirements of the species and that possible selection might produce strains of greater tolerance to drying.

FIG. 3. Wild rice in the mouth of a stream along the St. John River at Hamstead, New Brunswick. The water depth is about one and one-half feet at high tide.

Wild rice is naturally a fresh-water plant, but it grows successfully near the mouths of tidewater rivers in salt concentrations up to 0.1755% by weight. It is usually stated that if the water is salty to taste, wild rice will not grow. However, isolated clumps are often found in waters of salt concentration twice that listed above. Wild rice is completely absent from strongly alkaline waters as are sometimes found in the extreme western part of its range, succeeding best between pH 7.5 and 8.5, and

it is intolerant of sulphate, thriving only in an SO_4 concentration of less than ten parts per million and completely avoiding concentrations of more than 50 parts per million. Stagnant water is unsuited to the plant, and, although the current must not be perceptible, a constant change of water is absolutely necessary.

Distribution. *Zizania aquatica,* including its several varieties, has an extensive distribution in eastern North America, reaching from the northern end of Lake Winnipeg eastward along the northern shores of the Great Lakes and the St. Lawrence river to eastern New Brunswick, from the central Dakotas, western Nebraska and eastern Texas to the Atlantic Ocean, and along the coast as far south as central Florida. It does have a somewhat scattered occurrence west of this general range and has been reported locally as far west as the Rocky Mountains but apparently does not occur naturally beyond. Yet, it must not be supposed that even within its general range the species has a continuous distribution, for it succeeds only where its special requirements are met. Its occurrence is therefore greatly restricted.

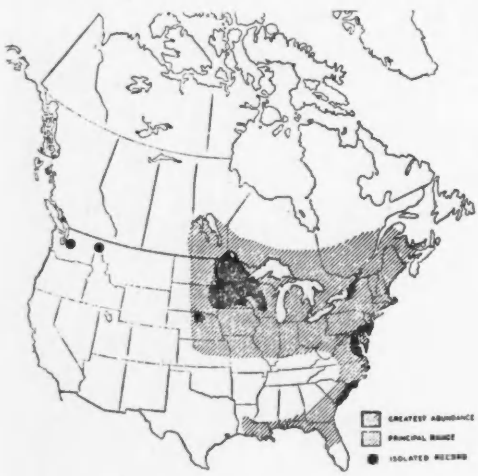

FIG. 4. Range of *Zizania aquatica,* including its varieties. (*From U. S. Dept. Agr., Tech. Bull. 634*).

The best stands of wild rice are found along the margins of tide water rivers of the Middle Atlantic states, above the saline zone and, more particularly, in the myriad of shallow lakes and ponds, and the numerous sluggish streams broadening occasionally into marshes in northern Minnesota and Wisconsin, and in adjacent areas in Ontario and Manitoba. In Minnesota alone there are estimated to be nearly 30,000 acres of wild rice in beds ranging from a few to several hundred or even a thousand acres in extent, and it often grows so densely that, in the words of one writer more than 250 years ago (6a), " in some places it is with difficulty that canoes can pass through obstructions they meet from the rice stalks ". The Michigan Conservation Department reports that there are over 20,000 acres of wild rice in that State, and it is also fairly abundant in other portions of the upper Mississippi valley. It is very common, too, in the province of New Brunswick.

Life History. As previously indicated, wild rice is an annual plant and the persistence of rice beds depends therefore upon spontaneous re-seeding each year. In autumn the mature grain falls from the parent inflorescence, with the palea and lemma attached and closely appressed to it, and sinks by its own weight, pointed end first. The barbs or bristles on the lemma and awn tend to attach the kernel to the soft mud until it becomes buried out of sight of the water fowl which feed upon it; it remains in this condition through the winter.

In spring, germination takes place, in Minnesota not until the middle of May, or even June, but near Washington as early as late March or the first week of April. The leaves which arise from the first one or two nodes of the young shoot are not like the mature foliage, but are narrow, limp and delicate in texture and float on the surface of the water. If the water level is high at this time and re-

mains so for a prolongd period, the floating leaves cannot reach the surface and the resulting growth is slender and weak. At this stage, even when conditions are normal, the seedlings are especially susceptible to the up-rooting action of wind and waves; and if weakened by the high water, they are almost certain to be wholly or partly wiped out. Moreover, any plants which survive would be lacking in normal vigor. This phenomenon, commonly referred to as "drowning", explains the failure of the crop where there are high and prolonged freshets.

It is interesting to note, by way of demonstrating the length of viability of the kernels, that in beds where an unusual spring freshet has wiped out the crop for one year so that no new grains are dropped, a heavy stand still appears the following year, indicating that a considerable quantity of the seed has retained its viability and has delayed germination for at least 18 months. This is a rather striking adaptation to an uncertain environment.

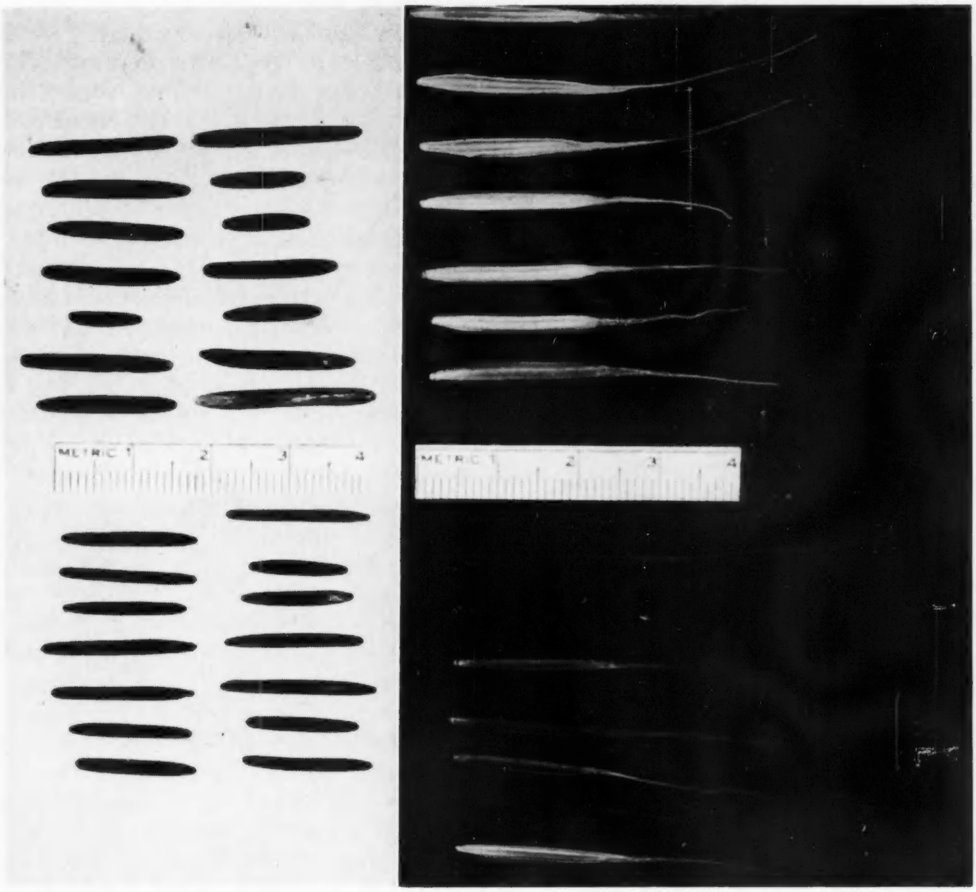

FIG. 5 (*Left*). Kernels of wild rice with palea and lemma removed after parching. The kernels have a groove on the lemma side. Upper, from Manitoba; lower, from New Brunswick.

FIG. 6 (*Right*). Kernels of wild rice with palea and lemma attached, as they fall from the panicle; some of the awns have been broken. Upper, from Manitoba; lower, from New Brunswick.

After three weeks to a month, the stalk rises above the water; and, with

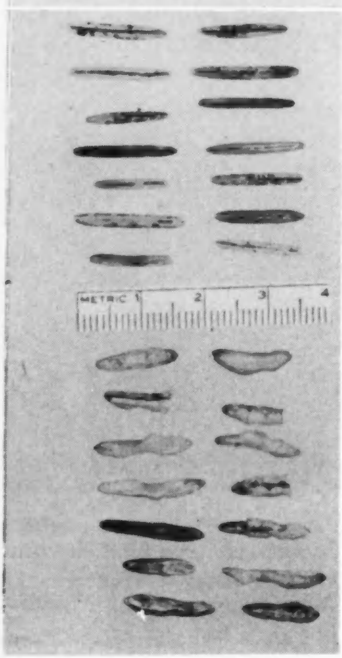

Fig. 7 (*Upper*). Sclerotia of ergot of wild rice, photographed from specimens provided by H. B. Williams. Mr. Williams exercises special precaution to prevent any of these from contaminating his marketed product.

Fig. 8 (*Lower*). Above rule, wild rice kernels which have been "polished" by remaining too long in the huller; rubbing of the kernels has removed their pericarps. Below rule, kernels which have popped as a result of being in the parcher too long.

appearance of the more characteristic upright leaves with drooping tips, the seedling foliage withers and disappears. Shortly thereafter, in the second or third week of July, when the stalks are a few inches above the water's surface, the panicles appear and the plants begin to flower; but the stalks continue their growth until the grains are nearly mature. The pistillate florets open first, while the males are still closed, and thus cross pollination is assured. The lodecules in the pistillate floret expand, presumably by absorbing water, and force the palea and lemma apart so that the stigmas protrude. After fertilization, the stigma withers and the palea and lemma close about the ovary as it matures. In some years there is no development of fruits in many flowers. The reason for this is unknown but is believed to be in some way related to the occurrence of hot dry weather when the plants are in flower.

By the fifteenth of August some of the grain is mature in the vicinity of Washington, D. C., and even in the north, ripening begins shortly thereafter, in spite of the differences noted in the time of germination in the spring. September is the wild rice month, and then, especially in the first two weeks, the bulk of the crop is harvested or falls back into the water. Not all the grains in any one panicle mature at once; instead they ripen in succession, starting at the tips of the branches, the whole process being completed usually within a week. In a large rice bed the ripening may cover a period of ten days to two weeks or even longer. As soon as the fruit is mature it falls at the slightest disturbance, so that if one is harvesting the crop, he cannot wait until it is all mature before collecting the grain, but must repeat the process several times. C. F. Chambliss (7), as an outcome of his studies on wild rice,

states his belief that there is sufficient variation in the ease with which the ripe grains drop to warrant attempts to select a strain which does not shatter so easily.

Natural Enemies. *Zizania aquatica* is frequently attacked by a species of ergot which has been named *Claviceps Zizaniae* (Farlow Herb. Collection). The ovaries are attacked shortly after pollination, and a hard purplish sclerotium is produced which might easily be mistaken for the true grain were it not for the fact that its diameter is three or four times as great. These sclerotia may be removed from the harvested grain by screening or by immersion in water, since the infected ovaries float, while the true grains sink. Commercial producers of wild rice are not always thorough in their inspection for ergot, and occasionally sclerotia may be found in the product which reaches the market. In addition to ergot, there are several other fungus diseases which attack wild rice, but the type and extent of damage are not described in the literature.

It is reported (18) that a caterpillar attacks the maturing grains of wild rice, making a small hole through the base of the lemma into the kernel and eating out the embryo so that, although two thirds of the caryopsis is left, it will not germinate. Severe attacks of this insect in Manitoba have been known to wipe out whole rice beds, and some damage, although much less extensive, is sometimes caused by it in Minnesota. The insect has been identified as the army worm, *Agrotis* sp.

Numerous species of duck and other water fowl prey upon wild rice, either consuming the grains after they have fallen or actually destroying the vegetative parts of the plant, sometimes with fatal results to attempts at establishing new beds. There are, as well, a number of smaller birds, especially the redwing blackbird and the bobolink, which eat the grains by picking them directly from the heads. Where muskrats are plentiful, they sometimes root out and eat the plants, but usually their depredations are minor. Finally, moose, deer and even cattle are extremely fond of the vegetative parts of the plant and often wade out to feed in rice beds.

Wild Rice as a Food Plant

Food Value. Before discussing the various aspects of wild rice as a food plant, it might be well to examine the nutritional properties of this grain and to make comparisons where possible with other cereals, to determine whether or not its widespread use as a food is desirable on a nutritional basis.

The part of the plant used as human food is the fruit or caryopsis which may be up to two cm. long and is usually dark gray or black. On the lemma side of the caryopsis is a groove, and beneath this is the embryo which extends from the base of the grain almost to its middle. On the palea side it is uniformly rounded with delicate longitudinal striations.

There have been several analyses of wild rice to determine its food value. That made by Prof. F. W. Woll in 1899 is especially interesting in that it showed wild rice to be more nutritious than any of the other foods to which its Indian users had access. The analysis in Table I was prepared in 1903 by Dr. C. F. Langworthy of the U.S.D.A. and was selected here because it not only indicates the way in which the grains analyzed had been prepared, but also gives comparisons in composition with the common cereals.

From Table I it will be seen that wild rice resembles the common cereals in its nutritive properties, although it is relatively high in protein and, like oriental rice, low in fat content. Kennedy in 1924 (25) showed that it further resembles the common grains in being relatively rich in vitamin B and relatively deficient in vitamin A and certain min-

TABLE I

COMPOSITION OF WILD RICE AND COMPARISON WITH OTHER GRAINS (4)

	Water	Protein	Fat	Carbon	Ash	Fuel value per lb.
						Cal.
Wild rice						
Whole grain	9.5	12.9	1.0	75.2	1.4	1,625
Ground	13.0	10.9	0.8	74.0	1.3	1,740
Parched whole grain[1]	11.2	14.6	0.7	72.3	1.2	1,620
Parched and ground	9.5	11.5	0.8	76.9	1.3	1,800
Rice, polished	12.3	8.0	0.3	79.0	0.4	1,630
Barley, pearled	11.5	8.5	1.1	77.8	1.1	1,650
Wheat, cracked	10.1	11.1	1.7	75.5	1.6	1,685
Oats, rolled	7.7	16.7	7.3	66.2	2.1	1,850
Corn meal, unbolted	11.6	8.4	4.7	74.0	1.3	1,730
Hominy	11.8	8.3	0.6	79.0	0.3	1,650
Kafir corn	16.8	6.6	3.8	70.6	2.2	1,595
Buckwheat flour	13.6	6.4	1.2	77.9	0.9	1,620

[1]The most commonly used form of wild rice.

eral elements. A later analysis (37) indicated that wild rice is especially rich in nicotinic acid, compares favorably with wheat, corn and rye in thiamin content, and is richer in riboflavin than wheat, corn, oats or rye.

As far as nutrition goes, there is every indication that wild rice is an excellent food, comparable in nutritive value to the common cereals in use today. Moreover, it is exceedingly digestible, and, for this reason, is often fed to patients suffering from stomach disorders.

Historical Use Among the North American Indians. It is not surprising that the aboriginal peoples of North America, finding within their domain a nutritious and palatable cereal which demanded no other labor than that of harvesting it each year, should have made great use of it and have come to rely heavily upon it. In fact, it would be cause for wonder if they had not. Just how widespread the actual use of wild rice was among the American Indians is a matter which has not been completely decided, but it is not incongruous with the known distribution of the plant to find references to its harvesting by the Senecas and other Indians of New York (Ind. Aff. Rept., 1870), to its use by the Seminole Indians of Florida who are reported by MacCauley, in his study of this tribe (27), to have gathered from the swamps all the rice they needed, to its consumption by the Kickapoos in Kansas (Ind. Aff. Rept. 1867) and the Seminoles and Creeks after their removal to the Indian Terrritory (Ind. Aff. Rept. 1870). In many of these reports, however, it is impossible to verify the claim that the plant named actually was *Zizania aquatica* and not some other grass locally referred to as rice. It is also highly possible that there were other peoples who gathered wild rice at some time and whose use of it never was recorded.

In none of the above mentioned cases is there any indication that the tribes actually gathered very much wild rice, or that they were dependent upon it; and this too is not surprising, for, although the plant is rather widely distributed, it is heavily concentrated only in a few areas. As previously noted, the region of most abundant growth includes central and northern Minnesota and Wisconsin and adjacent portions of Canada. This area, in particular that part of it east of the Mississippi and south of the Great Lakes, has been designated by Jenks

(24) as the wild rice district. In the larger sense, however, the wild rice district may be considered to include adjacent portions of neighboring States as well. So far as spontaneous vegetal food is concerned, no other section of North America is so characteristically an Indian paradise, and the importance of wild rice in the nutritional economy of the aborigines of this region makes its use by all others seem insignificant.

A. E. Jenks, in his extensive monograph of the wild-rice Indians (24), has given a detailed account of the history of wild-rice utilization. In the limited discussion which follows, based mainly upon his work, an attempt will be made to show the number of Indians who used wild rice at the peak of production, the tribes represented by the rice gatherers and the importance of the crop to them.

FIG. 9 (*Left*). A Chippewa Indian drying wild rice prior to parching at Tower Rice Camp, Minnesota. (*Photo by U. S. Indian Service*).

FIG. 10 (*Right*). Chippewa Indians harvesting wild rice at Nett Lake, Minnesota. The man in the bow poles the canoe while the woman in the stern knocks the ripe kernels into the boat. (*Photo by U. S. Indian Service*).

The Indians who inhabited the wild rice district at the time of the first arrival of the white men predominantly represented the two great linguistic stocks, Algonquian and Siouan. In the Algonguian tongue the name for wild rice is " mano'min " which is compounded of the two words, " meno ", meaning good, and " min ", meaning berry or fruit; in the Siouan language the general term for wild rice is " psin ".

The Algonquian tribes which gathered wild rice during some part of their history include the Chippewas (or Ojibwas), the Menomini, the Potawatomi, the Ottawas, the Sauk and Fox, the Maskotin, the Kickapoos, the Hurons and the Mississagua. Of these tribes the Chippewas and the Menomini were really the important ones. The Chippewas were the largest producers of wild rice, but the Menomini were, as their name suggests, the true rice Indians, and

as such they have always been known in Indian tradition as well as in authentic history. They were probably the first of the Algonquians to harvest wild rice and were dependent upon its use until recently when they became engaged in a profitable lumber business.

Among the Sioux, the Dakotas, the Winnebagos and the Assiniboin are known to have harvested wild rice. The Sioux were mainly plains Indians and, although the tribes listed above did depend upon wild rice to some extent at least, they never became so completely " rice Indians " as did the Chippewa and Menomini.

Fig. 11. A Chippewa Indian threshing wild rice at Little Rice Lake Camp, Minnesota. The threshing is accomplished by treading in a sunken basket. (*Photo by U.S. Indian Service*).

Estimates of the total Indian population of the wild rice district made by several travellers to the region between 1760 and 1825 vary so much as to show that they are not accurate. However, after an extensive study of these early references, which represent the only source of information available, Jenks has placed the total number of Indians who used wild rice at one time at approximately 30,000, and this he calls a conservative estimate. Moreover, the population estimates given by early observers demonstrate one important fact very clearly. When comparisons are made, it is found that the population per square mile within the wild rice district was several times that in other portions of the Northwest Territory. Since wild rice is the main attraction which sets this district off from the rest of the territory, it may be concluded that this plant was responsible for the greater population.

The importance of this grain to the Indians who inhabited the wild rice district arose from its use as a direct source of food and from the income derived from its sale to white men after they had come into the area. In addition, it might be mentioned that the congregating of water fowl to feed in the rice marshes in autumn greatly improved the hunting, and thus wild rice indirectly influenced the food supply in another way.

Among the Indians of the rice district, wild rice was their staple food, supplemented by hunting, fishing, the making of maple sugar and the gathering of berries; there was very little agriculture carried on. Jenks has expressed the opinion that the failure to develop an agricultural society on the part of these Indians is the result of the use of wild rice, since they had available an excellent grain food without any work of cultivation.

An affirmation of the importance of wild rice among the tribes considered rests upon evidence derived from three main sources. All of the early white travellers in the region have referred to the reliance of the natives upon this crop

as a staple and winter food. A second source of evidence is found in the insistence of the Indians of the rice area, when moved to reservations, that their new domains include stands of wild rice. The great suffering among the rice Indians which followed any failure of the rice gives further proof of the importance of this grain to its users. Reports of Indian agents tell of the great calamity which a crop failure brought in its resultant shortage of winter food; for, when they could not get rice, the Indians seemed unable to provide for themselves in any other way.

The studies which have been made indicate that extensive harvesting of wild rice has been carried on for only three to five hundred years, so that, although colorful, its history is not particularly long. On the other hand, one must take account of the possibility that tribes known to have occupied the area may have been preceded by others who have left no record.

History of Use by White Men. The Northwest Territory was a region abounding in fur-bearing animals, and the fur trade early brought hunters, trappers and buyers into the area. The Hudson Bay Company, the American Fur Company and the Northwest Company all operated extensively there during the latter half of the 18th century and the first part of the 19th when the trade was at its peak. In this great wilderness it was necessary for white men to obtain the bulk of their food supplies from the Indians, and in the wild rice district they bought large quantities of wild rice. It is recorded that the Northwest Company was accustomed to buy between 1200 and 1500 bushels of rice annually at about a dollar and a half per bushel for its several posts in the area, and the other companies obtained correspondingly large amounts. Rice was particularly valuable because it was abundant and easy to obtain, it was nourishing and palatable, and it was easily stored. Moreover, it was especially desirable to carry it on wilderness trips because of the high food value for small weight and bulk, and the ease of preparing it. The early explorers and missionaries in this region soon learned the value of wild rice and have left abundant praise of its virtues in their records.

Even after the passing of the frontier, and with it the great fur companies, wild rice continued to be used extensively by hunters, woodsmen and sportsmen, no longer from necessity but from choice. It was always a favorite in the lumber camps and remained a permanent part of the diet in the wild rice district, especially in the preparation of wild game. In the 1890's it began to appear in the local stores, in some places very abundantly. Sportsmen who came into the area to hunt learned to relish it with their game and began to ask for it in their favorite hotels and restaurants, where it soon became very common. Then it appeared in the markets on a national scale and soon became a household commodity, albeit only as a table delicacy because of the extremely high prices which it has always commanded.

Mythology. It is not in the least surprising that a profusion of legends should have grown up around a food plant of such great importance to its users as wild rice. The ideas of its origin vary from tribe to tribe and even from group to group within a tribe. In some of these traditions it is looked upon as a divine gift, and in practically all of them its discovery is regarded as more than mere chance occurrence.

The Menomini, who of all the tribes have been the most profoundly influenced by wild rice, appear to have possessed a knowledge of the plant from the very beginning of their tribal organization. According to their legend, Mänäbush, one of their many mythical half-god creatures, created the bear out of the

earth and of the bear made an Indian whom he called Skekatchekenan. This Indian then was established as leader of the bear phratry, the first section of the tribe, and to him Mänäbush gave a river (the Menominee), the fish in it, the sugar trees along its banks, and the rice which grew in its shallows, with assurances that he and his followers should always have these things. After the tribe developed a unified organization, these gifts became the property of the whole group. Remembering that they were promised that they would always have rice, these Indians have always refused to sow the grain, maintaining that such action would constitute a breach of faith.

Most of the Chippewa legends center around the mythical personality of Wenibojo, comparable to the Mänäbush of the Menomini, and his adventures. One account relates that Wenibojo discovered the grain while journeying alone, when a strange marsh grass saved him from starvation by calling out to him that it was good to eat. Another version of the Wenibojo legend describes how a wild duck dropped some kernels of an unfamiliar grain into his boiling pot. In any event, he immediately recognized the merits of the plant and introduced it to his people.

Another Chippewa legend is an account of a visitation which the Grand Medicine Man received from the "Great Spirit", in which a new grain was described that grew abundantly in the marshes, along with careful instructions for gathering and preparing it. The Winnebago believed that wild rice was given to them by the Great Spirit at the same time that they received maize.

The legendary origins of wild rice recounted here represent only the more common ones, and there have been numerous other versions which likewise attempt to explain the discovery of the plant.

Present Importance as an Indian Crop. At the present time, with the possible exception of the Menomini who may harvest a little for ceremonial purposes, the Chippewas are the only Indians who gather wild rice in any quantity. It is no longer a staple food with them, however, as it was for so long in the past, but it remains a most important supplementary food and a source of much needed income. In this connection Mr. Charles Wisdom of the Office of Indian Affairs in 1936 (56) wrote, "Rice is by far the most important cash commodity of the Chippewa", and again in the same article, "these people still look upon ricing as their most important activity, and even in cases where it is no longer profitable, they consider it the most desirable way of making a living". Except for small production for their own use, the Chippewa have never taken up agriculture, and their income is derived from the sale of berries, muskrat furs, craft products and especially wild rice.

Some idea of the importance attributed to this crop as a Chippewa industry is to be gained from an examination of the steps taken by the Federal Government and by the State of Minnesota to preserve and to develop this source of income for the tribe. During the early 1930's extensive work was done, particularly in various parts of Minnesota by the C.C.C. Indian Division, in the construction of improved camp sites near the rice marshes for the Indian harvesters. Such undertakings as the clearing of brush, the cutting of trails, the construction of sanitary facilities, the driving of wells and the building of log walks, canals and docks for ricing canoes and boats to unload were widely carried out. Certain run-out ponds were reseeded, and others which seemed favorable but contained no rice were planted. Artificial dams to prevent fluctuations in water level, which often cause crop failure, were constructed at several impor-

tant rice beds. In addition, the State of Minnesota bought up tracts of land around some of the rice lakes to overcome the difficulties caused by the prohibition of Indian camping by certain private owners. Some of the developments mentioned above were made on these State-purchased areas.

Assurance of a good market for the product and of fair prices for the Indian harvesters prompted several other undertakings. The Indian Office gave out instructions on methods of improving the product to make it more attractive to consumers. In **1936** the Department of the Interior approved the Chippewa Indian Cooperative Marketing Association, designed to handle the Indian crop with the greatest profit to the harvesters, and Congress approved a loan of **$100,000** to establish it. An elevator was built at Cass Lake, Minnesota, and the program was begun. Unfortunately, however, the enterprise failed. More recently a more successful Indian wild rice, arts, and crafts enterprise has been purchasing, processing and selling wild rice (**C7**).

Originally the harvesting of wild rice was an almost exclusively Indian undertaking, but, as it became more profitable, many white men entered into competition with the Indians, often with disastrous results. They often went to the rice fields too early, in an effort to get at the harvest before the Indians arrived, and the Indians were thus driven to similar practices. Rice stands began to dwindle because the grains which fell during the harvest and usually served for reseeding were not ripe enough to germinate. The white men often used broad boats which broke down the stalks so the rest of the grain did not mature for successive gatherings, and in some cases, it is reported, efficient mechanical harvesters which gathered too much of the crop were used and there was not enough left for seed. To remedy this situation laws were passed in Minnesota and Wisconsin, and regulations for harvesting in organized forest reserves were put into effect in Manitoba, but in the last mentioned case have not yet been consolidated into legislative form. In Minnesota the use of mechanical harvesters is prohibited; each harvester and his boat are licensed. The Commissioner of Conservation may close any stand to harvesting when he feels that it is in danger of being eliminated and needs protection. A director of the wild rice harvest is appointed annually, and it is his duty to recommend the opening and closing of such stands when he feels it necessary, to settle disputes arising in the harvest and to maintain contact between Indians and the Conservation Department. The Director has always been a Chippewa Indian. A general season is set each year for the opening of the harvest, but the exact date on each stand is determined by the Director and a committee of harvesters. Thus early harvesting is prevented. In addition, only Indians and residents on Indian reservations may harvest on rice beds within the reservation.

In Wisconsin the use of any mechanical device to cut or harvest wild rice in the bed of any stream without permission of the riparian owners or of any navigable lake, pond or bayou in the State without consent of the Conservation Commission, and the removal of any rice not yet mature from any such body of water are likewise prohibited. The rules in Manitoba apply only to forest reserves and have the following provisions. Only canoes and hand methods may be used in harvesting, and the date of the harvest beginning is determined by the forest officer. Each picker must have a permit, and records of all sales of wild rice must be kept and submitted to the forest officer at the end of the season. A five percent royalty is collected by the Province on finished rice sold through commercial channels. In addition, there

are certain rules pertaining to the use and care of camping grounds, and prohibiting the taking of game or game birds in the reserve.

Accurate figures on the total number of Indians who today derive at least part of their livelihood from the harvesting of wild rice are almost impossible to obtain. The figures which could be obtained were in most cases only estimates, and in such cases it is not always clear whether the number given is the total number participating in the harvest, just the harvesters, or perhaps only the number of permits issued, where such are required, and thus the number of boats involved. The summary given here represents an attempt to piece together a series of very fragmentary reports.

According to the Office of Indian Affairs (C7), it is estimated that over 3,500 families, almost entirely Chippewas, in Minnesota and Wisconsin annually participate in the wild rice harvest. Since these two States include almost all of the wild rice district in the U. S., this figure may be taken as the total for the country. This same source also estimated that in Minnesota the annual value of the crop to the Indians, based on average harvests and average prices, is \$100,000 for the rice gathered for home use, and \$300,000 for that harvested for sale. Similar figures given for Wisconsin are \$65,000 for home consumption, \$150,000 for the commercial crop. Thus it is again demonstrated that the annual wild rice harvest is of considerable economic importance to the Indians of the Chippewa tribe.

Estimates of the Indian harvest in Canada have been obtained from Indian agents in the wild rice district of Manitoba and Ontario through the Dept. of Mines and Resources, Indian Affairs Branch, in Ottawa (C6). In the Clandeboye Agency of Manitoba, where most of the rice in this Province is produced, it is estimated (C11) that 250 to 300 Indians take part in the annual harvest. This figure includes only the actual harvesters. The same source states that \$40,000 to \$50,000 is the annual income of the pickers, many of whom do not harvest for themselves but are hired to gather for white processors.

Reports from three rice-producing agencies in Ontario, where the crop is of sufficient importance to cause the agents to take notice of it, indicate that between 600 and 750 Indians participate annually. These figures are subject to the limitations of interpretation mentioned above. The importance of the crop in Ontario is indicated by a report from the agent at Sioux Lookout, Ontario (C13), in which it is stated that about five percent of the income of the Indians in this district comes from wild rice, and by a report from Kenora, Ont. (C12), in which it is estimated that each harvester would earn from \$200 to \$300 from the sale of wild rice. Adding these figures together, we see that in Canada between 850 and 1050 Indians harvest wild rice; the total number at least partially dependent upon this crop can only be guessed at by considering the families of these harvesters. This figure is at least roughly comparable with that given for the United States.

The figures of Indian harvesters given above cannot correctly be compared with the number 30,000 given by Jenks for the Indians who used wild rice at the peak of its importance as an Indian crop. This figure represents the total number of users, while the modern figure is roughly the number of families. Yet even though no direct comparison is made, it seems clear that the number of Indians deriving part of their livelihood from wild rice is far less now than it was two or more centuries ago. Moreover, it is quite clear that those still concerned with the crop are not so completely dependent upon it as were their ancestors. This considerable drop in im-

TABLE II
WILD RICE PRODUCTION

Location	Year	Total harvest pounds of processed rice	Estimated value
United States			
Minnesota (36, C10)			
	1940	1,586,000	
	1941	20,000	
	1942	337,000	
	1943	34,000	
	1944	400,000	
	1945	240,000	
	1946	400,000	
	1947	629,000	
	1948	1,155,000	
	Approx. Ann. Av.	500,000	$100,000 to $400,000 Av. $250,000
Wisconsin (C7)	Approx. Ann. Av.	280,000	$140,000
United States total		780,000	$390,000
Canada			
Ontario			
Ft. Frances Agenc. (C8)		40,000	
Kenora Agenc. (12)		60,000	
Sioux Lookout Agenc. (C13)		10,000	
Manitoba			
Calndeboye Agenc. (C11)		250,000	
Canada total		360,000	$180,000
North America total		1,140,000	$570,000

portance to the Indians can be traced to large scale removal of Indians from the rice area and to the development of other means of livelihood.

Present Status of the Wild Rice Industry

A consideration of the present importance of wild rice as an Indian crop has already been given, but an investigation of the over-all economic significance of the wild rice industry might profitably be undertaken at this point. Any attempt to determine the total wild rice production of North America encounters very grave difficulties. There is very little published information on this subject, and the only data available consist in general of estimates made by persons directly concerned with the industry. Minnesota provides an exception to this general statement, for in that State the policy of licensing all harvesters has enabled the Conservation Department to make fairly accurate determinations of the yearly harvest.

Table II brings together such information as could be obtained about wild rice production. Except for the figures given for Minnesota, the annual averages represent at best estimates of production for processed rice, and the total of 1,140,000 pounds for North America is unquestionably too low. This figure does not include the considerable quantity of rice harvested for seed purposes, and in large part does not take into consideration the thousands of pounds harvested by Indians for their own use and not recorded.

The figures obtained for Minnesota show a considerable variation from year to year. In certain years (*e.g.*, 1940 and 1948) the production in this State alone may exceed the total average production

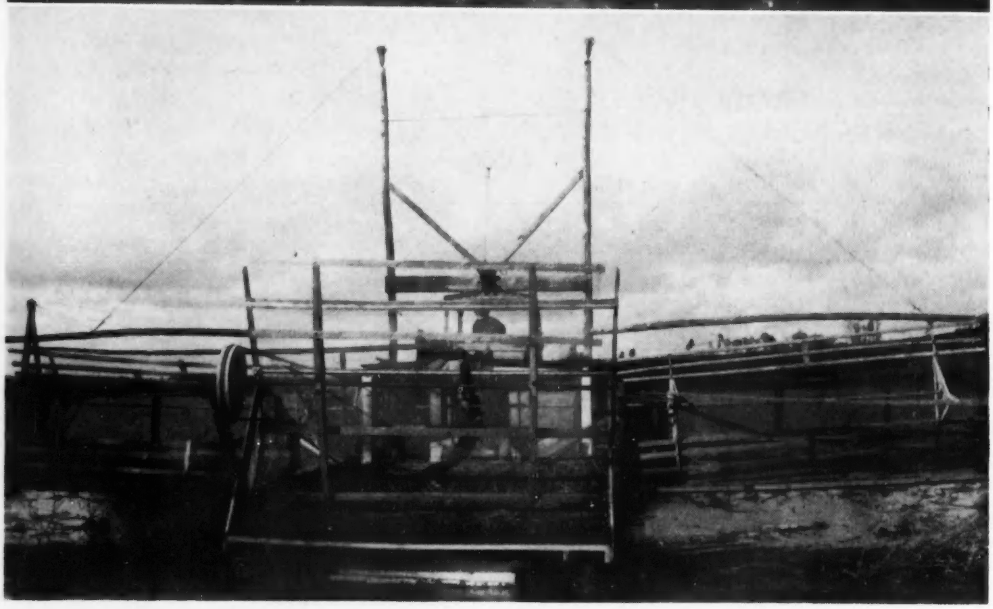

FIG. 12 (*Upper*). Side view of mechanical wild rice harvester used by H. B. Williams at Pointe du Bois, Manitoba. (*Photo by H. B. Williams*).

FIG. 13 (*Lower*). Front view of Mr. Williams' wild rice harvester. (*Photo by H. B. Williams*).

for all of North America, and in other years (**1941** and **1943**) the crop may be an almost complete failure. These failures probably result from an unusually high water level in the spring. The Minnesota Conservation Dept. estimates that in any four-year period the harvest can be expected to fail once and to produce one bumper crop and two fair crops.

It would be most difficult to make

comparisons with amounts of rice harvested in former times by the Indians. In the first place, the only figures of early production are provided by Indian agents, and more frequently than not they neglected to include the rice harvest in their reports. Moreover, the figures are almost always given in bushels and there is no standard weight for a bushel of wild rice (estimates vary from 30 to 60 lbs.), and it is never stated whether the rice referred to is processed or not. Moyle (36) has estimated that at present in Minnesota, at least twice as much rice is harvested each year as was commonly gathered annually between 1860 and 1900, when Indians gathered and processed it all; but this reference makes no effort to consider the relationship to the harvest in the days of its peak Indian production.

Any estimation of the actual value of the wild rice crop must necessarily be based upon the price obtained for this product. For this reason the available information on prices of wild rice at various stages of production over a period of years is summarized in Table III. The estimated values of the wild rice harvest in Table II are based on a wholesale value of $0.50 per pound for processed rice. The total value for North America, given as $570,000, is unquestionably too low for the same reasons that were given in the discussion of the total production figure. It is interesting to note the rather general increase in the prices at all stages of production from the beginning of the table to the end.

At the present time Minnesota and Manitoba are the centers of flourishing and growing wild rice industries. In Minnesota licensing figures show that each year approximately 2500 persons participate in the harvest. Much of the crop is handled by members of the Minnesota Wild Rice Producers Association, a social organization of independent white buyers and processors maintained to help promote and develop the industry (C5). In Manitoba the industry is expanding rapidly, and there is at present under way a program to increase production and to improve the quality of the product, even to the extent of introducing a grading system similar to that used for commercial grains. It is estimated that the annual production in Manitoba for sale may reach 1,000,000 pounds in the near future, for there are

TABLE III

PRICES OF WILD RICE IN VARIOUS STAGES OF PROCESSING

Year	Price per pound green rice, paid to harvesters	Wholesale price per pound processed rice	Retail price per pound processed rice
1915		$.05 (Manitoba) (C16)	
1927*		$.08–.15 (Minnesota) (C5)	
1929*	$.03 (Minnesota) (39)		
1939	$.06–.11 (Minnesota) (39)		$.50–.75 (Minnesota) (39)
1940 1941 1942 1943	$.05–.12 (Minnesota) (36)	$.20–.40 (Minnesota) (36)	$.40–.60 (Minnesota) (36)
1946		$1.25 (Minnesota) (C15)	
1947	$.20–.35 (Minnesota) (C5)	$.60–1.50 (Minnesota) (C5)	$1.50–2.50 (United States) (C5)
1948	$.20–.35 (Minnesota) (C5)		
1949	$.10 (Manitoba) (C11)	$.40–.60 (Manitoba) (C12, C17)	
	$.12 (Ontario) (C8)	$.25 (Ontario) (C9)	
	$.10 (Ontario) (C12)	$.20 (Ontario) (C13)	$1.20–2.35 (United States) (C11)
	$.20–.35 (Minnesota) (C5)	$1.00 (Minnesota) (C5)	$1.50–1.75 (United States) (C5)

*Date only approximate

extensive stands of wild rice which are not now harvested. At the present time, most of the Manitoba crop (150,000 to 200,000 lbs.) is exported to the United States.

In 1941, studies were made by the Minnesota Dept. of Conservation to determine the total and the actual average yield of wild rice per acre. The total yield was determined by sampling in measured areas. It was found that unless the total yield is over 300 pounds per acre, it is not profitable to harvest (750 pounds unprocessed). Usually the actual take is between 30 and 40 pounds per acre and is sometimes as high as 50 pounds. A mechanical harvester reported from Manitoba (C16) may gather as much as 60 pounds per acre and can be used profitably where hand harvesting would be out of the question. The difference between actual take and total yield results from incomplete harvesting of individual heads and incomplete coverage of the stands. It will be seen that there is certainly plenty of grain left after harvesting for seed and for the water fowl which feed on the rice.

There is every indication that the wild rice industry will continue to increase in the years to come. The quality of the product is constantly improving as a result of improved processing methods, and its popularity is correspondingly expanding. Wild rice is especially popular for serving with wild game so that its extensive use has been concentrated in the hunting season; but the widespread use of frozen food lockers for game is now spreading the market over the entire year. The increasing interest of State and Provincial governments in this new and expanding industry with corresponding precautions against depleting the stands by excessive or improper harvesting will in all probability insure the processors a continued supply of wild rice.

Primitive Indian Methods of Production

The methods by which the American Indians gathered, and to a certain extent still do gather, their annual crop of wild rice and prepared it for use as food, has attracted more attention in the literature written about this plant than has any other phase of its history or economic importance. This interest has certainly been justified, for the Indian methods of production provide a perfect example of the way in which primitive people learn to perfect special methods for particular food plants. To Jenks (24) this process seemed to be near the bottom of the ladder of agricultural practices, its production being largely confined to the harvesting and care of the grain. There have been occasional reports of Indians sowing the grain, thereby establishing new stands for harvest, and of weeding unwanted plants from the rice marshes during the growing season, but such practices seem rather to have been the exception than the rule. As for the actual harvesting, many writers have implied that this was a rather uniform process among all of the rice Indians, but Jenks' extensive treatment has shown that, although general practices were the same, there was a great diversity in the actual execution of details.

Wild rice matures in the latter part of August or in September, the bulk of the harvesting falling in the first two weeks of the latter month. Among the Chippewas, the Dakotas, the Ottawas, the Menomini and possibly others, it was a fairly common practice for some of the Indian women to go to the rice beds ten days to three weeks before the grain matured and to tie some or all of the stalks into bunches. This was done by gathering a number of stalks together into bunches, without pulling them up, and wrapping them with a twine made of the inner bark of basswood. The bundles

were usually formed in straight rows. There seems to have been several reasons for doing this. Grain thus bound did not fall or shatter so easily and could thus be left until fully mature so that it could all be gathered at once. When bound, the grain was less liable to be lost as a result of the jarring action of winds or rain, and it was effectively protected from the ravages of small birds. Moreover, in some tribes, whatever grain an individual bound became her property, and this process may well have been a means of securing some of the best locations in advance of the general harvest. It should be noted that the process of tying was far less common than direct harvesting, and it is likely that part of the rice crop was often tied so that it could be left with very little loss until after the main crop had been gathered.

The actual process of gathering the rice was also usually performed by the women, although in some tribes the men assisted or did all the work. This lasted about a month, and during this period the families moved to the edge of the rice marshes. The exact time of beginning the gathering was a matter of great importance because if delayed too long the rice would be lost through shattering, and if begun too soon the kernels would be detached with great difficulty and those which fell back into the water would be too immature to germinate so that the stand might eventually be wiped out. The grain is properly gathered just before full maturity. The date of the opening of the harvest was decided by the chief or the tribal elders with severe penalties for violations.

In the harvesting process the canoe was indispensable except in very shallow water where the rice was sometimes gathered on mats spread on the surface. The usual procedure required two individuals in each harvesting canoe. One sat in the bow and poled the craft with a forked pole, so as not to sink too deeply into the mud, and the other sat in the stern facing forward with two sticks, two to three feet long and usually of cedar, with which to harvest the grain. As the canoe moved back and forth in regular fashion, the harvester would reach out, first on one side and then on the other, with one stick, and bend as many stalks as possible over the canoe. With the other stick she would strike the heads sharply enough to detach those kernels which were reasonably mature. The grains fell into the canoe which was usually lined with a blanket. When one end of the canoe was full, the two occupants changed implements and filled the other end. It is estimated that about a bushel an hour could be harvested in this manner, and one canoe load, varying from 75 to 200 lbs., was considered to be a day's work. Since not all of the rice on a given head ripened at one time, and different plants matured at different times, it was necessary to repeat the harvest at intervals of a few days over the same area. The harvesting method just described actually gathers about 50 percent of the grain, the rest falling back into the water to become the seed for next year's crop.

There were a number of variations on the general method of gathering wild rice, a few of which are worthy of note. In the first place, if the rice had been previously tied, it was necessary first to untie each bundle and then to beat the grain into the canoe. It is reported that sometimes whole heads of rice were gathered, or heads with about two feet of stalk attached were cut and tied into bundles. Certain of the Wisconsin Chippewa customarily stripped some green rice with the fingers, and parched it for immediate use before the actual harvest began.

Since the rice grains drop very easily when fully ripe, it is always necessary,

as previously noted, to gather them just before full maturity is reached. For this reason, if the grain is to be kept without fermentation, it is necessary to dry and cure it. Fresh rice does not have a particularly pleasing flavor and curing serves to improve this greatly. Moreover, in fresh rice the hulls (palea and lemma) are extremely tenacious and can be removed effectively only after curing.

The Great Lakes Indians widely employed three types of curing: *a*) prolonged sun drying, *b*) smoking and heating over a slow fire, *c*) parching in a vessel.

The first method, that of sun drying, is of course the simplest, since it merely involves spreading the grain on strips of bark or on blankets in the sun for several days, with frequent stirring to allow even curing. The grains in this process became black or at least very dark and the flavor was poor. This method was little used except by some of the Dakotas who favored it for its simplicity.

The second method, that of curing the grain over a slow fire, was usually done on a scaffolding of varying length and width, but mostly three to four feet high, built of poles with slabs laid across the top. The Dakotas were accustomed to build one 20 to 50 feet long and eight feet wide, but usually they were somewhat smaller. Grass or mats were sometimes spread over the slabs, and the rice was put on top, usually to a depth of three inches. A slow smoky fire of birch or tamarack was built beneath the rack, and the rice was left with occasional stirring for one to three days, during which the smoke and heat cured it. The grain thus produced, called hard rice, was greenish-black, much darker than parched rice and requiring longer to cook. The flavor qualities of this rice were rather poor, but the Dakotas, Winnebagoes, Chippewas and Menomini used this method because it was easy and the keeping qualities of the grain were very good.

The process of parching was the latest to be adopted, it is believed, but it is undoubtedly the best so far as flavor and lightness of color of the processed grain are concerned. Although it is the most laborious of the processes, it has long been preferred by the Chippewas. In historical times this tribe used to smoke most of the crop but produced some high quality rice by parching for ceremonial and other special uses. Fully four times as much was smoked as was parched because of the labor involved. At present practically all of the crop is parched.

In parching, about a peck of rice is put into a kettle of copper or iron (probably other receptacles were used before trade with the white men was so common) over a fire and heated rather strongly for 15 minutes to a half hour until the husks become dry and brittle. It is necessary to stir constantly with a special slender wooden paddle, for if it overheats in any one place, the rice will become too brittle or will pop, that is, the kernels will crack open and the white interior can be seen. It is customary first to dry the rice in the air for a short time to remove water picked up in harvesting.

After curing by any one of the three methods described, the hulls are dry and brittle and may be rubbed off without much difficulty. There have been three important methods by which this can be accomplished: *a*) treading, *b*) pounding with a pole of various forms, *c*) flailing.

In the process of treading, which is still in rather widespread use, a hole was dug in the ground one and one half to two feet deep and two to three feet in diameter, and was lined with clay, the skins of animals or with wooden staves around the sides and a round slab in the bottom so that the whole looked like a sunken barrel. Approximately a peck of cured rice was put into the hole. Then a man (for this was the only operation which the man always performed himself) climbed into the hole and, support-

ing most of his weight on props of various sorts erected beside the hole, proceeded to tread the rice by a rhythmic movement of the whole body coupled with shuffling of the feet, the weight alternately being thrown first on one foot and then the other. This caused the grains to rub against one another and the husks were thus rubbed off. Usually the treading was done with the treader wearing a new pair of moccasins, but sometimes it was done barefoot. Often the rice was completely tied up in a skin before treading. The Ottawas usually treaded rice in a ditch, the Dakotas used a wooden trough, while other groups sometimes employed a barrel or basket above ground for the operation. The Chippewas of northern Wisconsin combined curing with threshing, placing the fresh rice on a fresh deer skin stretched over a low fire and having a small boy tread it while it was curing.

Although the Chippewas have always been partial to treading because it causes less breaking than any of the other methods, they and the Menomini often used the process of pounding with a pole. The cured rice was put in a lined hole and was then agitated by working up and down in it either a pointed or a blunt-ended pole five and one half to eight feet long, so that the grains rubbed against each other and the hulls were removed. Sometimes the grain was later subjected to treading for complete removal of the hulls.

In the third process, flailing, the grain was put in a skin or woven sac, or spread on a blanket and beaten with flails until it was separated from the hulls. The Menomini and the Winnebago erected a cloth screen on three sides and threshed the grain by sitting on the open side and beating it with two sticks. Among the Menomini 15 to 25 bushels were often dumped into a ditch, with a screen on each side, and beaten with sticks.

After the threshing was completed it was necessary to winnow the grain to separate it from the useless hulls. This was usually done in trays of birch bark about 30 inches long, 20 inches wide and six or more inches deep. The women always performed this skilled operation which was effective even when there was no wind. The tray, containing about a peck of grain and hulls, was held waist high. It was then lifted several inches and at the same time carried out from the body. Then the motion was suddenly checked, and the basket was lowered quickly and brought back toward the body. The chaff tended to pile up at the outer ends and to spill over. This was the method most used by the Chippewas; however, some of this tribe as well as the Menomini poured it from basket to basket or from a basket to a sheet of bark, the wind serving to blow the hulls away. It was also common to spread the rice out and blow the chaff away with a fan. It requires about two and one half pounds of green rice to produce one pound of parched and cleaned rice.

The season of the wild rice harvest was a time for social events as well as for solemn religious observances, as whole villages, or even tribes, congregated at the edges of the marshes. Among most of the rice-gathering Indians, the September moon was called "the wild rice moon", and the Dakotas even derived the name of the October moon from this plant.

Among the Menomini it was customary to hold a feast the night before the gathering began, at which time prayers for fine weather during the harvest were given and offerings of tobacco were made to propitiate the gods. The Chippewa of Canada held a similar feast before the harvest, and others of this tribe each year celebrated what was called a "manomin feast" after the rice harvest and before the winter hunting began. This was really a thanksgiving ceremony, and wild rice was the main food consumed. The first rice of the season gathered by the

Dakotas was carefully processed and set aside along with the first maize, and the first of every other product which they used as it came into season, for an annual "first feast", a most solemn affair in which only those who had the distinction of having killed an enemy might participate.

As the Indians of the rice district have departed somewhat from their older customs and the rice industry has become largely a commercial enterprise, much of the old ceremony of the harvest has been dropped, but some groups of the Chippewa, especially on reservations where the tribal organization is maintained, have clung to the traditional customs. For example, one writer (**42**) as late as **1943** records his observations of a traditional harvest feast in northern Minnesota.

Property rights in the wild rice beds were carefully respected by most of the Indian tribes. Usually each village or band had its own particular fields to harvest, and within the common holdings family privileges were recognized. The Dakotas usually assigned part of the common fields to each family or small group of families, which might be harvested untrespassed. Among the Chippewa, families held certain areas by pre-occupation, the right to a certain tract being handed on from generation to generation; and if a man sowed a new bed, it became permanently the property of his family. Tribal enemies, however, constantly usurped these holdings and in such cases may have determined the outcome.

Modern Improved Methods of Production

The Indians who today harvest wild rice, although they still follow in a general way the traditional methods of harvesting and processing developed by their ancestors, have made some innovations which are worthy of note. Where white men have become interested and have entered into the industry, some very ingenious devices have been perfected to facilitate production.

Among the Indians the process of tying preceding the harvest, never very widespread anyway, has all but been abandoned. As for the actual harvest, except for the introduction of two-prowed flat-bottomed boats along with the traditional canoes, and the participation of men in the harvesting, the procedure has changed little since historical times.

White men in Minnesota and Wisconsin who harvest rice are required by law to confine themselves to these procedures. In Ontario and to a certain extent in Manitoba they follow the same techniques; but there are in Manitoba a number of mechanical harvesters which seem to be operating successfully.

Mr. H. B. Williams of the Williams Wild Rice Farm, Pointe du Bois, Manitoba, a large scale harvester and processor of wild rice, has been using mechanical harvesters of various designs since **1917**. He has very kindly provided photographs and a description of the apparatus he is now using. This device is mounted on a scow, **32** feet long with an eight-foot beam, powered by an **80**-H.P. automobile engine and propelled by two six-foot paddle wheels. There is a differential between the paddle wheels with brake drums attached for steering, so that no rudders are needed. On each side of the scow are "outriggers", in the form of wire mesh cages, open to the front. Revolving arms of a reel, like those used on old grain binders, five feet six inches in diameter, gently hit the rice heads when passing over them, knocking the rice kernels onto the tables in the bottom of the cage. The kernels are then carried into the boat by means of oscillating rakers, where they are bagged. There is also a third reel on the front so that the coverage is nearly complete.

This harvester is operated by two persons and can gather up to 500 pounds per hour if the crop is good.

There are also in Manitoba a number drives the single 8- to 16-foot reel on the front. These smaller devices can harvest between 1,000 and 6,000 pounds of rice per day.

FIG. 14 (*Upper*). Wild rice-processing plant operated by Mr. H. B. Williams at Pointe du Bois, Manitoba. The long building in the right foreground is the drying shed; parching is done in the low-roofed attachment at the rear of the shed; threshing is performed in the building on the hillside.

FIG. 15 (*Lower*). Inside view of the curing shed at Mr. Williams' plant, showing 50,000 pounds of rice spread out to dry prior to parching. (*Photos by H. B. Williams*).

of smaller machines operating on the same principle. These are generally mounted on two small boats or freighter canoes and operate with about a ten-H.P. outboard motor. Another motor

Mechanical harvesters of a type similar to the smaller models described above were used in Minnesota prior to the passing of the 1939 law which bans their use. It was stated that the me-

chanical harvesters were too efficient and did not leave enough rice for seed. This difficulty has apparently not appeared in Manitoba, although some reseeding is done. Indeed it is reported (C16, C11) that the mechanical harvesters actually improve the crop by stirring up the mud with the paddle wheels. This apparently assures better covering of the seed and may also have the effect of bringing fresh mud to the top. Possibly the deleterious effects in Minnesota resulted from too early harvesting by machine operators in an effort to outsmart the Indians.

There are two distinct advantages of the mechanical harvester over hand picking. With it, it is possible to harvest profitably where hand picking would not pay. Also it can be used for a third picking, giving extra production where hand picking would not be attempted. Moreover, the uniformity of the blows of the reel to the rice heads ensures a much more uniformly ripe product than hand picking can ever provide.

Disadvantages are noted in the inability of the machine to operate in very shallow water or in lakes with submerged sharp rocks. It is also not effective along river banks or where there is an appreciable current. Experience in Manitoba has shown that best results are obtained by using a combination of mechanical and hand picking.

The Indian rice harvesters have made some improvements in the methods of processing. Now all the rice is parched, following a preliminary drying. Galvanized washtubs, tilted on edge, or even special sheet-iron troughs have replaced the older copper or iron kettles. Some of the Indians use a mechanical parcher—an old steel oil barrel, rotating on a central shaft, with the rice inside, over a low wood fire.

Removal of hulls is most frequently accomplished by treading, the other methods having largely gone out of use. Sometimes a hole is dug, as in former years, but more often now the treading is in tubs or in special concrete troughs. In Minnesota some of the Indians use mechanical hullers which consist of a stationary barrel in which is centered a revolving shaft to which are attached paddles shod with pieces of old automobile tire casing. The end of the shaft is connected by a belt to a gasoline engine or to the rear wheel of a jacked-up automobile. Often it is hand turned by a crank. The hulls are removed as the rice is thrown back and forth against the paddles. Such small devices can easily be carried into the field and will process from 500 to 1,000 pounds of finished product a day.

The conventional methods of winnowing are still used, although some Indians have adopted the use of regular fanning mills, such as are used for grain. In Wisconsin and Minnesota it is estimated (C7) that between one-fourth and one-half of the crop is still Indian processed by the old or slightly improved methods. In Manitoba (C11) the estimate is about one-third.

As the demand for wild rice grew, a number of white men in the rice district went into the business of buying processed rice from the Indians in the field and re-selling it, perhaps after first packaging it. In attempting to enlarge their markets, these buyers frequently encountered complaints that their product was not uniform and contained too much extraneous matter, such as hulls and parts of leaves or stalks, and that it was often too much or too little parched. It became apparent that if the business was to expand, a clean and graded product was needed. To accomplish this, many began to buy the grain unprocessed from the Indians and prepare it themselves by improved methods. However, there are still many buyers who purchase the Indian processed product.

The first machines were rather crude

and were of the type mentioned as being used by the Indians today. Many such small outfits are in operation today throughout the wild rice district. There has been a consistent effort to improve the quality of the product by improving the processing equipment, especially in Minnesota and Manitoba. This has led to the development of larger stationary processing plants which handle a large volume of product. Such a plant is operated by the Williams Wild Rice Farm of Pointe du Bois, Manitoba, and a description and photographs have been provided by Mr. Williams (C16). The rice for this plant is supplied by the harvester described above, together with hired Indian pickers.

After harvesting, the rice is dried for three to six days, and turned every 24 hours for the first two days and every 48 hours thereafter to avoid heating or mold. It may then be parched. If the field is distant the rice is packed loosely in jute bags for shipment, and the bags are moved every day.

The parchers are engine-driven rotating drums, ten feet long and three feet in diameter. Two drums rotate in a concrete furnace over a fire. Care must be exercised that the rice is not over-heated so that it pops. When parched it is emptied out and the steam allowed to escape.

Next the rice goes to the hullers which consist of cylinders 24 inches in diameter with rotating cores of rubber-covered spokes. Suction apparatus takes away the hulls as they are loosened. Then the rice passes over screens in a grain cleaner to remove broken rice or chaff that might have escaped the suction in the hullers. The finished product should be 85 to 90 percent whole. It is bagged in 100-pound sacks. In 1949 the production of this mill was 60,000 pounds.

FIG. 16 (*Left*). The filling end of the parchers used by H. B. Williams. Two drums, ten feet long and three feet in diameter, rotate over a fire in the concrete furnace.

FIG. 17 (*Right*). One of the hullers used by Mr. Williams being emptied. Inside the cylinder is a rotating core with rubber-covered spokes which threshes the rice. (*Photos by H. B. Williams*).

In Minnesota similar stationary mills have been established. One of the most modern is that operated by Mr. Roland Hicks at Grand Rapids, Minnesota. In this plant the green rice is first dried on the floor of a well-ventilated shed. There are three parchers in operation in the Hicks plant, each consisting of a single stationary drum over a fire, inside which the rice is constantly agitated by arms

on a turning shaft. When a charge is completely parched, it is dumped out through the open top by turning the drum down. As in the Manitoba plant described above, after parching, the grain is hulled in a drum containing revolving arms, and cleaned in standard grain-cleaning equipment. There are several other producers in Minnesota who operate modern processing plants of this sort.

A word must be said about the Chippewa Indian Cooperative Marketing wild rice for human consumption is that which is Indian parched in the open over a hard-wood fire where it takes in the smoky flavor". On the other hand, the rice processors are enthusiastic about the quality and cleanliness of their product. For example, one company writes in an advertising booklet (54) "—modern food science has taken over the processing to ensure perfect sanitation and uniformity of product". There can be little doubt that the trend in the modern industry is toward the second point of view.

FIG. 18 (*Left*). The finished product spilling from the grain cleaner onto a conveyor belt which carries it to a bin for bagging. The photo shows Mr. Williams picking out ergot that escaped the screens.

FIG. 19 (*Right*). The rice being put into 100-pound bags for shipment.

Association which operated on a different plan. This organization bought the rice processed and merely refinished and graded it before packaging or selling in bulk. The enterprise failed, largely, it seems, through inability to develop a market (C10). It might be suggested that perhaps the lack of market resulted from the inferior quality of the product as compared with the machine processed rice. In this connection it is interesting to note that some believe the Indian product to be of finer quality. One observer (C2) writes, "The truly good

Methods of Preparing Wild Rice for Food

The rice-gathering Indians perfected many methods of preparing this nourishing wild food, and it is stated that they relished it in a variety of forms. Very often, especially on extended journeys, the parched rice was eaten with no further preparation at all, or was merely roasted on hot rocks.

The commonest method of cooking wild rice was boiling, often by pouring boiling water over it repeatedly until

tender. If twice as much water as rice was used and the mixture was boiled strongly, the resulting mass had the consistency of oatmeal. This was very much relished, especially if flavored with maple sugar or dried berries. Sometimes berries of various sorts were boiled with the rice, and a special delicacy was prepared by cooking the grain in water seasoned with grease of various sorts of game. Stews and soups were a favorite food and were prepared by cooking the wild rice with meat or with its broth, venison, wild fowl, fish and even dog meat being the commonest stew bases. Wild rice, corn and fish boiled together produced Tassimanonny, a concoction which became famous among the whites who sampled Indian cookery. There is even a record from 1840 of a war party of Chippewas who prepared a victory feast by cooking some of their slain Sioux enemies with wild rice.

There were a number of other less widely used preparations which are worthy of brief mention. Popped rice could be prepared by stirring the grains in a pan of fat over a slow fire. One rather unusual soup consisted of rice cooked in the sap of the woodbine. Finally, the rice kernels, pounded or ground, provided excellent soups and were also used as a baby food.

Varied though the Indian's modes of cooking wild rice were, the white man has far surpassed him in devising tempting ways to prepare it for consumption. Yet this profusion of cooking methods is not the result of a desire to mask the natural flavor, for it is estimated that 90 percent of the white men who have tried it have liked it, but instead represents an attempt to make use of its rich and somewhat rice-like qualities in a variety of ways.

It has been found desirable, before using, to wash the grains thoroughly in several changes of cold or luke-warm water, and even to rub them between the palms to remove any dirt and to get rid of the smoky accumulation; and indeed the Indians themselves were accustomed to clean the grain in this manner. However, rice which has been processed by the modern mechanical devices does not require this operation.

Wild rice first made its reputation on the white man's table as a stuffing for game birds because it possessed what has been described as "that gamey flavor", and the number of suggested preparations of wild rice stuffings indicates that this is still its most important role. On the other hand, boiled or steamed, it makes an excellent vegetable, and cooked in this manner and served with sugar, cream and possibly fruit, it has long been offered at fine hotels as Canadian Breakfast Food. It boasts of one virtue not common among breakfast foods, in that when re-heated and served it retains its original flavor without deterioration. A brief survey of advertising booklets and current magazine articles has yielded a list of 45 recipes for the preparation of wild rice, ranging from game-bird stuffings to tempting desserts.

Wild Rice as a Natural Food for Migratory Waterfowl

As civilization has spread across this continent, the draining of lakes and marshes for agriculture, the polluting of streams with industrial wastes and the reshaping of natural water bodies in irrigation and flood-control, which have accompanied it, have wrought great havoc in the natural haunts of migratory water fowl. Satisfactory breeding grounds and suitable resting places along routes of migration have become increasingly scarce in recent years; and this deficiency has been evidenced in the poor hunting which has followed in its wake. The alarming reduction in the game bird population has attracted the attention of many; and sportsmen's associations, both local and national in scope, as well as

State conservation departments and the Federal Government, have undertaken to remedy the situation.

The rigid regulation of hunting to protect the game birds from wholesale slaughter has been a widely adopted measure, and an effective one. At the present time, however, it is being supplemented by a more positive program in the re-establishment of dwindling breeding grounds and resting places, thus favoring an increase in waterfowl population. In any such attempt provision of both adequate food and satisfactory cover for the birds must be considered; these requirements are best supplied by the introduction of certain types of aquatic plants into ponds and marshes, in some cases artificial, where they do not now occur, since plants supply a very large part of waterfowl food and are the most important providers of cover.

The planting of game food plants also has another function, that of attracting migratory waterfowl to specific localities, thus providing better hunting in those areas. This latter objective is more selfish in nature but does little harm, provided the hunting is not excessive; at the same time it is helpful in meeting the former objective. It is widely carried on by individuals and by local game clubs.

Recent widespread interest in game conservation and attraction has led to a great demand for those plants which are the natural food of migratory waterfowl. This demand has been met, in part at least, by the establishment, during the last 25 years, of a number of aquatic nurseries which specialize in supplying game food plants. One such firm, contacted in preparation of this paper, supplies 33 of these plants. Each year, as research indicates that others are valuable, they are added to the growing list.

The early explorers in the rice area were the first to realize the value of wild rice as a game food plant, and they have left countless comments on the abundance of wild ducks in the rice marshes when the grain was ripe. Modern research has shown more precisely the value of wild rice as a natural game food. Although it appears not to be so important as formerly supposed, there are many who believe that its chief claim to consideration as an economic plant rests upon this use.

In 1911 the Bureau of Biological Survey published the results of an investigation into the foods of 16 species of important game ducks in the United States (30), using the method of stomach analysis. Those portions of the results which pertain to wild rice, indicating the percentage of this grain in the stomach contents of each species, are shown in the table at top of p. 137.

A later investigation, published in 1939 by Martin and Uhler (29), considered the foods of game ducks in the United States and Canada, and consisted of an examination of the stomachs of 7,998 ducks of 18 species. They found that wild rice supplied 1.95 percent of the total food used by these birds and ranked ninth among the foods. The variance between this and the average given above probably results from the fact that in the latter work a larger area was covered and more species were investigated.

In either case the total figure seems to be rather small for a plant which is ranked so high as a game food. In order to interpret this discrepancy, several other points must be considered. Wild rice is extremely important for certain species, notably the mallard, black duck and wood duck, all very important game birds. It is the fact that several other species use no wild rice that pulls the general average down. Furthermore, wild rice is not distributed over the whole area reported on; actually it is concentrated only in a small part of it.

Common name	Scientific name	Number of stomachs examined	% of contents composed of wild rice
Mallard	*Anas platyrhynchos*	209	17.13
Black duck	*A. rubripes*	51	12.05
Gadwell	*Chaulelasmus streperus*	37	....
Baldpate	*Mareca americana*	30	7.16
Green-winged teal	*Nettion carolinense*	126	4.56
Blue-winged teal	*Querquedula discors*	86	3.46
Shoveler	*Spatula clypeata*	48	....
Pintail	*Dafila acuta*	67	4.95
Wood Duck	*Aix sponsa*	75	11.62
Redhead	*Marila americana*	60	4.41
Canvasback	*M. vallisneria*	60	.33
Scaup or bluebill	*M. marila*	67	1.26
Lesser scaup	*M. affinis*	126	7.49
Goldeneye	*Clangula americana*	23	....
Bufflehead	*Charitonetta albeola*	36	2.22
Ruddy Duck	*Erismatura jamaicensis*	41	....
Average			4.78

A fairer picture is obtained when one examines the regional figures given in Martin and Uhler's publication (29):

Region	% of total food	Rank
Atlantic Coast	2.61	8
Eastern United States & Canada	5.10	3
Eastern Canada	9.58	3

This regional breakdown shows that wild rice is much more important in some areas than the total figures would indicate. Moreover, although wild rice is utilized to some extent at all seasons, it is available in abundance only in autumn. At that season it is a far more important food than the figures given above indicate. For example, on some Minnesota lakes it may comprise 50 percent of the diet of some species. One must also keep in mind that this is the migration season, when travelling birds are badly in need of stopping places well supplied with food. In addition, wild rice is an important source of food for geese.

Recently, Stoudt (53) has shown that the stomach analyses of mallards in Minnesota do not necessarily indicate their food preferences, for hunters and rice harvesters often drive the ducks from the rice marshes to less preferred but safer sources of food; and that analyses of unmolested ducks consistently show higher percentages of wild rice than do those taken in unprotected areas during the hunting season. Previous workers seem largely to have overlooked this factor in their studies.

Wild rice is eaten at every stage of its development, but the main food supply is derived from the ripened grains which are obtained after they have fallen. The birds tip up or dive for the kernels, dibbling them from the mud of the pond bottom. In deep water the birds are severely handicapped in this respect. It has been unofficially reported by one observer that, when the stalks are very short, as it sometimes the case with var. *angustifolia* in Canada, the ducks reach up and strip the ripe grains from the head.

Although most important as a source of food in autumn, it has been determined that wild rice kernels are available at practically every season of the year except, of course, when the water is frozen. This is because germination may occur at any time up to 18 months after the grains have fallen and because, as has been previously shown, a fairly

large proportion of the grains is delayed for some time. Young shoots and germinating seeds have been found in the stomachs of ducks at practically every season.

In addition to the kernels, the young shoots are eaten by many species, and the flowers are consumed by the wood duck. Four hundred of these have been found in one wood duck stomach. Moreover, the leaves and stalks of the mature plant are eaten by geese.

Since the figures given vary so much, it is practically impossible to determine the exact status of wild rice as a game food. It is probably not, as was long believed, the most important; yet it is one of the leaders. Constant spreading of the plant by people interested in game birds bids fair to increase its importance as the area of availability is increased.

In considering the importance of wild rice to migratory waterfowl, there are two other factors which must be taken into consideration. Dense stands of this tall grass provide excellent cover which is a requirement of any good resting place or breeding ground. In this respect wild rice is much better than many other of the important food plants. In the second place, wild fowl, especially ducks, are extremely fond of wild rice and flock to the marshes in autumn in great numbers, where, as the previously quoted figures from Minnesota indicate, they feed in large measure on rice. At this time they turn away from their more common foods to the preferred rice. Since the time of ripening generally corresponds with the hunting season, wild rice makes an excellent game attractant and is widely used by gun clubs wishing to improve their shooting.

Studies undertaken by Stoudt (53) on the food preferences of mallards in the Chippewa National Forest of Minnesota show that the heaviness of the wild rice crop in that area clearly determines whether or not a large flight of mallards will stop in the forest.

As the importance of wild rice to migratory waterfowl conservation has been discovered, there has been an ever increasing attempt to spread it into areas where it does not now grow, or to make it more plentiful within its present range. There are strong indications from the attempts already made that the plant could be introduced widely and that it does not at present occupy all suitable locations. Successful introductions have been made in Texas, California, Washingtcn, northern Nevada, Arizona and Nova Scotia, to mention only a few, and in numerous localities within its present range as well. On the other hand, many attempts were complete or partial failures, especially before the problem had been thoroughly studied. These failures have been attributed to two main causes, namely, unfavorable conditions for growth of the plant and improper handling of the seed between its gathering and subsequent sowing. As for the former point, the ecological requirements of wild rice have already been discussed in detail and need no further consideration. On the other hand, proper handling of the seed is a matter which must be examined, since faulty practices have probably caused the greatest number of failures.

The main point to be emphasized is that the seed must be kept constantly moist from the time of harvest until sown. If the seed it allowed to dry in storage or in shipping, it will almost certainly lose its viability. For many years this fact was not recognized, and some plantings were even made with parched grains. The amount of drying which the kernels can withstand is not precisely stated, and there is some variability; in general, however, two or three days is about the limit if germination is to be unimpaired. Fyles (18), working in Canada, found that fully matured grains, not exposed to direct sun after harvest, could be stored dry for two to three weeks and still maintain 50 percent ger-

mination. The occurrence of occasional grains which resist even prolonged drying suggests that selection might develop strains which could be handled more efficiently.

There are a number of suggested methods for storing the grain for long or short periods; in all cases the grain must be kept moist and relatively cool. The simplest method is to store the rice in open barrels or pails out of doors in fresh water which is changed daily until it freezes. This is ideal for small quantities. Freezing does no harm unless the temperature is reduced to a very low level, in which case the damage is suspected to be largely due to desiccation.

For larger quantities the rice may be stored in open vats with constantly changing water in cold storage at temperatures just above freezing. Tests made by the B.P.A. (13) indicate that after 393 days under such conditions from 80 to 88 percent germination may be expected. If cold storage facilities are not available, large receptacles may be anchored on the bottom of the streams where the plant grows, with perforations for water exchange. Sometimes special concrete vats are constructed on stream bottoms. One fact which must be constantly kept in mind is that, after cold storage, the grains are much more susceptible to drying damage than before and must be handled with increased care. Another suggested method involves storing the grain in burlap bags packed among blocks of ice and the whole covered with sawdust which is kept constantly moist.

It might be interesting to consider briefly the method employed by a firm which handles wild rice seed. The following processes are used by the Game Food Nurseries of Oshkosh, Wisconsin, and the account of them has been supplied by their naturalist, Mr. W. O. Coon (C2). The seed is harvested in the traditional manner, but at the close of the day it is bagged in burlap sacs and submerged in water without any processing. The seed is picked up as soon as possible and hurried to warehouses where it is placed in wet refrigeration at about 35° F. The bags are placed on racks in such a way that one bag does not touch the next, for it has been found that if wet bags touch one another for even a short time there is a tendency to heat which destroys germination. The ceiling of the storage room is lined with coils without drip pans; the moisture which condenses on these coils is allowed to fall on the bags, thus keeping them moist. In December the seed is taken out, for if left longer the close packing which results favors growth of mold. The bags are emptied into tanks, the seeds are soaked in water and thoroughly stirred until the grains are well mixed cross-wise. They are then re-bagged and the temperature of the storage room is set at freezing, for it has been reported that freezing tends to increase the percentage of germination. The seed is removed and shipped as ordered.

Wild rice for seed may be shipped in the dry state, but if any reasonable percentage of germination is desired it should be kept moist. The seed may be shipped in jars of water, but this a cumbersome method; usually it is packed in moist sphagnum, excelsior or coconut fiber in a loosely slatted box. If the distance is great, temperatures near freezing should be provided. Sometimes young plants are shipped and set out, but this is less commonly done.

It is possible to avoid the storage problem by sowing the rice as soon as possible after it has been harvested in autumn, using what is often referred to as " Nature's method ". There are, however, three main objections to this procedure: *a*) depredations of waterfowl are especially great in the fall; *b*) during winter and early spring much mud and debris may be washed in from the shore, burying the grains too deeply for germination; *c*) floating ice and the high water

of spring often carry the seed away. It is now felt that, even if seed is readily available in the fall, it is better to store it over winter and sow it in the spring.

The sowing is done from a boat by broadcasting the grain upon the water, distributing it as evenly as possible. It is estimated that 50 to 60 pounds per acre will give a good stand. It is better to sow in selected areas such as sheltered coves and allow the plant to spread wherever it can in succeeding years.

Studies carried on in Michigan (35) show that most wild rice plantings in that State (74 percent of fifty investigated) have failed to establish successful permanent stands, although the seed was properly handled and conditions appeared to be suitable. Similar work in Minnesota (36) showed planting results to be only fair. The failures in Michigan were attributed, in part at least, to fluctuating water levels. A conservation expert in New Brunswick advises against further plantings of wild rice in that Province because he believes that the plant is already established wherever it can grow successfully. These negative results suggest that at least reasonable caution should be exercised in attempting to spread wild rice for use as a game food and attractant.

Several attempts have been made to introduce wild rice to foreign countries, especially England where it was hoped it would provide a food for game birds and possibly become a crop for otherwise waste land. However, the plant has not been particularly successful in that country, apparently because the summers are not hot enough for it to flower and fruit properly; it dies out after a few years.

Miscellaneous Uses

Muskrats are extremely fond of wild rice vegetation, and the plant is often introduced into marshes to attract these animals for trapping. Cattle graze upon wild rice, and the stalks are sometimes, though not frequently, cut for forage. Moreover, the plant, especially when in flower, is unusually attractive, and for this reason has at least a limited use as an ornamental in aquatic gardens.

Summary

An attempt has been made to consider wild rice from as many aspects as possible and in particular to investigate its present economic importance. The wild rice of North America is *Zizania aquatica* L., which includes several varieties, the number depending on the taxonomic treatment followed. Although widely distributed in eastern North America, the plant is restricted to localities where its particular requirements are met. There are a number of natural enemies which cause more or less damage to the crop.

As a food plant, wild rice is of interest because of its former use by several tribes of American Indians; its present importance in the economy of the Chippewas; its value to the early explorers and fur traders; and its present status as a widely appreciated delicacy. Although it is still harvested, and in many cases processed, by the unique primitive methods first devised by the Indians, a number of improvements have been developed and their use is increasing. The State of Minnesota and the Province of Manitoba are at present the centers of a small but growing wild rice industry.

Wild rice is especially valuable as a source of food and cover for migratory waterfowl, and it is being extensively introduced, especially along routes of migration. As a game-bird attractant it is unsurpassed.

The future of wild rice as an economic plant seems assured, at least in its capacity as a game food. There are a number of steps, however, which could be taken to increase its usefulness. The variability of the plant suggests the pos-

sibility of selecting strains of greater tolerance, of increased resistance to drying out of the seed, or even with the ability to grow in terrestrial locations—all of which would facilitate its wider utilization. If it were possible to develop a non-shattering strain which would retain its kernels until all or nearly all were ripe—and the known variability of the plants suggests that this might well be accomplished—wild rice might even have agricultural possibilities.

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Sugar-Cane Breeding in Java

Hybridization work and commercial introduction of many new clones into the sugar plantations of this island have resulted in a tenfold increase in sugar production on an acreage basis since 1840.

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Historical Sketch

One of the most impressive examples of what can be accomplished in agriculture by improvement of planting material is furnished by the sugar-cane industry in Java. Sufficiently exact data exist on the yields since 1840 so that they allow computation of the annual average yield per ha (hectare) since then, expressed in its equivalent of cristal sugar. If the annual figures are put into a graph, the latter shows a continuous general rise, with only temporary slight interruptions of short duration followed every time by a conspicuous rise. Those conspicuous increases correspond to the introductions of new clones, of new " seedling kinds " as they are called by the practical planter. The average yield of sugar per ha for Java was two tons (of 1000 kg) in 1840; in 1910 the average had increased to ten tons, and in 1940 it was nearly 20 tons, so that it had increased tenfold in a century. Part of this increase must admittedly be attributed to improvements in the growing technique. In the course of years the Sugar Research Institute has tightened its grip on the crop, especially under the direction of Dr. Ph. van Harreveld (1912–1926) who accomplished much in this respect, work which does not appear so clearly in the publications and reports of the Institute but which became apparent by the rise in the general level of cultivation.

As other factors which contributed to the increase in yield, we must recognize improvement of irrigation and intensification of technique, for instance, by better determination of the degree of ripeness of the cane and, in a small measure, by restriction of the production area, under which not only the fields of poorer soil were the first to be abandoned but also the producer was enabled to adapt his milling operations better to the optimal stage of maturity as the capacity of the factory surpassed the requirements. Although all these factors have contributed toward the progress noted, the main factor has been improvement of the planting material, which is very evident from the fact that every time a new improved clone was introduced into the industry, the yield per ha showed considerable increase.

The great impulse for this work came from a serious threatening of the crop by a disease, the so-called " sereh-disease ", which made its appearance rather suddenly all over Java about 1880 and which in the beginning made planters and financiers fear that the sugar industry was doomed. Sometime previously a collection of cane varieties had been brought together, and it was decided that a scientific worker, Dr. Soltwedel, should be in charge of it. In 1887 he was the first in Java to raise sugar cane from seed, with seeds of yellow Hawaii-cane (Kobus, 1893, p. 17). By this work the

foundations were laid for the research work which in the following years became such a brilliant success. Improvement of planting material has always formed an essential part of this work and has given results of the highest importance for sugar production. The history of it has been described by Bannier (1926, p. 545) in an excellent review which has furnished most of the data for the following summary. Additional details were supplied largely by Dr. O. Posthumus, Director of the General Agricultural Experiment Station in Buitenzorg, Java, formerly in the Sugar Experiment Station in Pasoeroean [1].

Heretofore it has not been possible to determine the exact nature of the sereh-disease. It has been described as a virus disease, but opinions diverge on this point. It is the more remarkable that soon after its appearance, a simple means for controlling it was found. At altitudes of 600–700 m (roughly 2000 feet) the disease does not develop, and when the cuttings for laying out new fields are taken from plantings at such altitudes, they remain for some time free from the disease, to such a degree that a field laid out with " berg bibit " (planting material from the hills) can reach maturity without suffering from the disease. This method was recommended as early as 1887 by Soltwedel (Jeswiet, 1928, p. 186). The sugar mills, generally established in the lower plains, always planted hill-bibit. Special businesses were started for producing and selling such materials; in other cases the mills themselves established fields in the hills to furnish them with healthy cuttings. In this way fields could be planted suffering little from the sereh disease, but the purchase or production of cuttings from the hills and their transport occasioned rather high expense which has been figured at several millions of guilders per year. There is still a second serious disease, which has to be attributed to a virus, the so-called " mosaic disease ". In serious cases it may cause losses of 20% of the crop.

When in 1887 Soltwedel had discovered the possibility of growing cane from seed, this method was soon tried for obtaining better planting material. In the East-Java Sugar Research Institute (Proefstation Oost-Java, POJ, at Pasoeroean) Wakker obtained a seedling in 1893, which received the number 100 POJ. It had originated from a cross between two known varieties, in reality clones, Bandjarmasin hitam × Loethers. Gradually some of the producers of hill bibit also started crossing work when they saw that good profits could be made with an eventually valuable new " seedling kind ". In this way 247 B, obtained by the planter Bouricius, came on the market in the beginning of this century; somewhat later EK 28 and DI 52. All these clones were obtained by crossing existing ones, and they were superior in yield to the older clones, such as Black Cheribon.

From the very start there was a dual purpose in making selections of sugar cane, namely, to increase the yield of sugar per ha and to increase resistance to disease (Wakker, 1893), as Rümke explains in a well documented historical review of the interspecific crosses of *Saccharum* (Rümke, 1934, p. 212). In 1890 Kobus was sent on a mission to India to search for new forms of cane which would meet these requirements. He collected 18 forms which were planted out in a quarantine station in Banka. In 1896 the best ones among them were introduced in Java at Pasoeroean. One of these was the Chunnee-cane, a thin fibrous cane, afterwards called *Saccharum barberi* by Jeswiet. This form appeared to be very resistant to sereh-disease and was used from 1897 to 1910 for a number of crossings with cultivated

[1] This excellent versatile scientist survived the Japanese occupation of Java, but was kidnapped by Indonesian nationalists in November 1945 and has been heard of no more.

canes from Java, such as Black Cheribon and Striped Preanger. These latter forms are called " noble canes ", and a hybrid carrying their blood is said to be " nobilized "; in reality such a hybrid is a back cross with noble cane. The once " nobilized " Chunnee hybrids were resistant to sereh disease, they had a strong root system and showed resistance to extreme growing conditions, but they were only moderate producers and had other less desirable characters, for instance, susceptibility to the virus mosaic disease. Therefore they could not compete with the noble canes, such as 100 POJ and 247 B. To overcome this difficulty the Chunnee hybrids were crossed among themselves; the resulting new seedling kinds were somewhat better but remained susceptible to stripe disease, and when they became available for distribution, even better new noble kinds had already been obtained. About 1912 nobilisation of the Chunnee was more and more abandoned; at present it is used no more in breeding work. From 1912 to 1916 many seedlings were raised by selfing the noble canes and also by crossing these among themselves, but when they were tested they were found to be too susceptible to diseases.

Crossings with Kassoer

In the days of Soltwedel there existed in Java, apart from the Chunnee cane, another sereh-resistant form, the " kassoer " cane, which was intermediate in its characters between the wild species glagah (*Saccharum spontaneum*) and the cultivated forms. It was found as a wild plant by Krüger in Cheribon (Jeswiet, 1916, p. 383) and at first was thought to be a species by itself. Already in 1893 it had been used for making crossings with noble canes, but without striking results. In 1911 Miss Wilbrink, then of the staff in Pasoeroean, again made crossings of Black Cheribon and 100 POJ with kassoer (Jeswiet, 1928, p. 195); after two years some forms were kept in the collection in Pasoeroean. They were resistant to sereh- and stripe-disease but had rather thin stems and therefore gave too low yields. One of these hybrids, 2364 POJ, was destined to play an important role, but Miss Wilbrink's work was not continued for some years.

In 1915 Jeswiet studied the characters of kassoer, and by comparing them with those of other forms he came to the conclusion that kassoer was a hybrid of glagah and some cultivated forms (Jeswiet, 1916, p. 1343).

In 1917 artificial crossings of both were carried out. The hybrids so obtained closely resembled the kassoer form in all their characters; they were therefore called " synthetic kassoers ". They were once nobilised glagahs. These and the twice nobilised seedlings derived from them appeared to have taken over the disease resistance, the strong root system and the vigorous growth of the kassoer, and at the same time the better habit and higher yield of the cultivated cane, although not in a sufficient degree to be suitable for planting. When they were nobilised a third time, very productive forms were obtained, which still kept the high resistance in a satisfactory measure.

Since not much progress had been made in the period 1912–1915, Dr. van Harreveld, then Director of the Pasoeroean Institute, the botanist Dr. Kuyper and the breeder Dr. Jeswiet proposed a new programme for the seedling work, in which limiting it to crossing aimed at special combinations was given up and a much larger number of hybrid forms was included. Whilst up to 1915 the number of new combinations in any one year was always less than one hundred, the figure that year rose to 163, and since then it has been 200 or more every year. The greater the number of combinations, the greater the likelihood of obtaining some which seem promising. This is better realised when it is remembered that of approximately 400,000 seedlings

raised in the period 1913–1925, very few of them have become valuable acquisitions.

When the hybrid character of kassoer had been found, this hybrid and the seedlings derived from it were used for further nobilisations. As a noble cane for these combinations, the then popular EK 28 was chosen and also some others. In 1917 the first crossings were made with 2364 POJ (100 POJ × kassoer), one of the best seedling kinds of the twice nobilised series of Miss Wilbrink from 1911. This kind had a very good habit, vigorous growth, a strong root system, good foliage and a rather fair yield in comparison with other forms of the same descent. What rendered this form especially valuable for crossing work was the fact that it transmitted all these desirable characters to its seedlings, something which is far from general with these forms. The hybrids with 2364 included a certain number of valuable new kinds (2722, 2725, 2727 and 2753) which certainly would have taken an important place in sugar production if they had not soon been surpassed by the wonder cane 2878 POJ. In some other sugar-producing countries, such as Puerto Rico, Formosa, Argentina and Louisiana, 2725 POJ has become one of the main clones out of this series. Data may be found in some studies by Posthumus (1928, p. 1145 and 1929, p. 96).

These first results showed how good progress could be obtained by using 2364 POJ in crosses, and so the work of nobilising was continued, using EK 28 as the noble parent. Among the seedlings obtained in 1921, the famous 2878 POJ was found, which has only ⅛ of glagah "blood". Obviously this does not mean that the glagah characters are manifest only in 12½% of them. When tested, 2878 was found resistant and highly productive. The clone quickly became very popular and was responsible for an increase of many tons in the average yield per ha.

The resistance against sereh-disease was so high that it is no longer necessary to use cuttings from the hills (bergbibit). The consequence was that the industry could save the cost of laying out fields in the hills for producing the cuttings or of purchasing hill cuttings from the producers of this material, and further, the heavy expense for transport from the hills to the plains, a saving which for the whole industry amounted to several millions of guilders per year. Also, the seedling sorts produced in subsequent years appeared to be wholly resistant, and it may be stated that for Java, sereh disease is a thing of the past and that the younger generation of planters does not even know what the disease looks like. It may be added that the new clones at the same time possess a strong resistance against yellow stripe disease; they are not absolutely immune, however, for occasionally a small spot of this virus disease has been found on a leaf, but there has never been measurable damage of even what might be called an attack.

A sister seedling of 2878, numbered 2722 POJ, was also quite a good form in respect to transmitting its characters. It was crossed again with EK 28, and in this way 2940 POJ was obtained; this hybrid contained only 1/16 "blood" of glagah. This appeared to be too low a percentage, at least for the growing conditions in Pasoeroean, where the soil consists of a stiff clay and the climate is characterised by intensive dry periods. On the other hand, this nobler but less resistant clone was well suited for more favourable growing conditions, under which it gives higher yields than 2878.

This fact suggested to Posthumus, who was in charge of the breeding work in Pasoeroean those years and who wanted to obtain a seedling without the too great susceptibility of 2940, that further backcrosses of 2878 might be worthwhile, not with a noble cane but with 2940 which already contained 1/16 kassoer.

In this way he obtained hybrids of 2878 (with 1/8 kassoer) × 2940 (with 1/16 kassoer); so in total with 3/32 kassoer. Such a hybrid is 3016 POJ which gives a yield a good deal higher than 2878, but which at the same time possesses enough resistance to be an excellent clone for cultivation. The new clone 3016 POJ has in recent years replaced 2878 POJ on many estates, with the effect that the average yield has been raised from 16 tons per ha to the 20 t/h level.

In summarizing the work for improvement of sugar cane in Java, it may be briefly stated that at the start it consisted of a search for more productive seedling kinds of the existing noble canes and then of combining the more resistant and at the same time better yielding hybrids of noble cane and kassoer cane by back-crossing second generation hybrids with noble forms or with hybrids in which the noble cane had the largest share. As simple as these few words are, they record the hard work of a number of excellent scientists during half a century. Hundreds of thousands of seedlings were raised and studied. The great value of the work has been that a vast experience has been accumulated with the various forms, not only of their worth for direct use in agriculture but also on the question of how far they transmit their valuable characters to their offspring.

Future Breeding

The more complicated work of crossing and back-crossing, referred to in the foregoing historical account, became too difficult for the man of practise, who, as long as the crossing was done only between varieties of noble cane, had been able to obtain such good improvements as EK 28 and DI 52. For the more systematical crossing of successive generations of hybrids, in which the noble forms and the wild ones have to be combined in varying degrees, continuity is essential, and such investigations can be best pursued by an institution like the Sugar Research Institute of Java.

The centre of breeding activity has shifted to this Institute which carries out the crossing work, first selection of the most valuable seedlings and preliminary testing of them, and which has supervision of the whole work, but it is also the organisation of the industry at large that has been important in attaining ultimate success. The Institute at Pasoeroean has organised an extensive service of experiment fields on the estates themselves, and with the aid of this service the new clones can be tested in a short period and after successful examination rapidly distributed to the whole industry. An example can best show the scale on which this testing work is organised. When searching for the best kinds out of a set of new ones, Posthumus once had an experiment in which 90 new clones considered sufficiently promising were compared with two standard clones which at the same time were re-examined regarding their value under growing conditions. The question arises: Can this improvement work continue? Probably not all possibilities in the available material have been exhausted, but it is evident that there must be a limit to the increase of yield. The amount of solar energy which reaches one ha of cane during one growing season is not infinite and so can furnish sufficient power to the plants for combining only a limited quantity of carbon, hydrogen and oxygen into sugar. Also, the progress obtainable by giving fertilisers and irrigation water has its limits, determined by the law of diminishing returns, as Wilcox among others has explained in a strong argument. There is a limit to the quantitative effect of nitrogen, phosphate, potash, water, sunlight, depth of the furrow, planting distance and all the other factors required for growing the crop (Wilcox, 1937, p. 175).

In seeking additional improvement, there is always the question as to whether

the available noble sorts and wild resistant forms have been used to the utmost. In 1928 a group of American scientists under the lead of Brandes and Pemberton, who were joined by Jeswiet, explored New Guinea for indigenous forms occurring there. Some new forms were found and have been introduced into sugar-producing countries, among which Java received a set of the new sorts. Especially good canes were not among them and it is thought that all the valuable ones had already been collected. More than 80 years ago a collection was established by Krajenbrink, a pioneer planter in this field, who, by sending out more than 60 requests, brought together material from Java and Madoera, and also from South-Celebes, the Riouw-Lingga archipelago and from Malaya. He thought that this collection contained from 12 to 15 varieties (Posthumus, 1932, p. 1015). These were all forms of the tropical "noble" cultivated sugar cane, *Saccharum officinarum* L.

Forms of Saccharum

It may be useful to insert here a review of the various forms of *Saccharum* and to give a short sketch of their classification. A distinction can be made first between the cultivated cane, *Saccharum officinarum* L., and the wild species, *S. spontaneum* L., to which the often cited glagah belongs, a wild form indigenous in Java.

The cultivated canes can be divided into two groups:

a) The real tropical cane, mentioned above as the noble kind which has its centre in New Guinea and the Moluccas. It is planted in New Guinea by the primitive tribes inhabiting the island, and it is possible to distinguish different varieties. The stems are thick, often with barrel-shaped internodes, soft, juicy and coloured. Under favourable growing conditions these forms often give high yields, but they are sensitive. They have a tendency to low tillering and their root system is weak. To this group belong the older cane forms, such as Black Cheribon, Loethers, Striped Preanger and the older improved clones obtained from seedlings of Striped Preanger, the so-called seedling kinds, such as 100 POJ, 247 B, EK 28 and DI 52.

b) A group of cultivated ones, with its centre of distribution in northern India and characterised by hard green stems rich in fibre. They are resistant and give noteworthy yields under less favourable growing conditions. The internodes are long and narrow, tillering is good and the root system is strong. This class contains a number of Indian forms, divided by Barber into eight groups. To these belong the Chunnee cane, introduced by Kobus into Java, as mentioned above, and the so-called *Saccharum sinense* Roxb. which includes the form known as Uba cane. *S. sinense* is not, as the name suggests, a Chinese form. Closely allied to these forms is the Indian Puree cane, called "Yellow Egyptian cane" in Java and known in the New World as "Creole cane". The internodes of this Creole cane are slightly thicker and somewhat barrel-shaped, so that this form comes nearer to the noble kinds. This whole group of the Chunnee cane must perhaps be considered as a different botanical species or as a subspecies of the tropical cane.

In contrast to these two groups of cultivated canes stands the wild species, *S. spontaneum*, represented in Java also and known there as "glagah". It has a very large area of distribution, being found as a wild plant from Algeria to the eastern part of Indonesia and in the Philippine Islands. It shows a great many forms. In north Sumatra, Borneo and New Guinea *S. spontaneum* is represented by tall vigorous specimens; the forms indigenous in Java are smaller.

In Celebes and the Philippine Islands there are other forms which differ in physiological characters from the Javanese kinds. In the north of India there

exist types of this wild cane which do not form tall stools but tufts (hussocks), from which the flowering stems arise. In Turkestan similar types have been recorded which are frost resistant. All these forms of the wild cane have in contrast with the cultivated kinds, a common character in containing little juice and therefore, even if the sugar content of the juice be high, giving almost no sugar.

Allied to the glagah are a few other forms with little sugar. One of them is the teboe salah of Borneo, Celebes and New Guinea, which is somewhat thicker than the common glagah and also shows colouring, thereby slightly resembling the noble canes, but which differs from them by its low sugar content. Another is the so-called *Saccharum robustum* of New Guinea, Fiji and New Caledonia, also with some colouring and resembling a thin noble kind, but also practically without sugar. This cane was found in **1928** in the wild state in New Guinea by the Brandes expedition (Mangelsdorf, **1933**, p. **2632**). Glagah is considered an archetype. It displays greater variability in the eastern part of the archipelago (New Guinea) than in Java. In New Guinea we find, for instance, forms with red leaves. Posthumus has brought together a number of forms of glagah from the wild, indigenous in Celebes, Borneo, etc. Bremer has investigated their cytology and found great differences in chromosome numbers (Bremer, **1934**, p. **156**). It is thought that the Indonesian cultivated forms have originated by mutation from the wild glagah.

Spread of Improved Clones

Distribution of cultivated cane over the rest of the world took place from India with the forms grown there, especially of the "Puree-cane", mentioned above as the "Yellow Egyptian" of Java and the "Creole cane" of South America. The initial material for this distribution came from India by the old trade routes to the countries around the Mediterranean Sea. It is still cultivated there, and one traveller from Indonesia, who visited Beyrouth some ten years ago, saw the "Yellow Egyptian" cane offered as a chewing cane in the market place there.

From the Mediterranean area this cane went to the Canary Islands. In **1493** Columbus took it from there to the New World; it might be called, therefore, after the explorer who introduced it, "Columbus-cane". According to others the cane was introduced into America somewhat later and by others. The first West Indian sugar was made in **1509** in San Domingo. From there the cane went to Mexico (**1520**), Brazil (**1532**) and Peru (**1533**). In all probability it was the only one for two and a half centuries in the New World. Only towards the end of the **19**th century did the noble cane arrive there (Stevenson, **1940**, p. **303**), when in **1780** noble kinds were sent from Java to St. Eustatius and Surinam (Dutch Guiana) (Posthumus, **1928**, p. **1150**).

All the forms cultivated in Java generally belong to the noble tropical cane. Hybrids have been made with the cultivated forms from India, but these, although more resistant than the noble cane, yielded much less than the noble kind. This applies as well to the hybrids with Chunnee as to those with the so-called *S. sinense*. Only the wild kassoer, found by chance in **1887**, has proved to be of high value for hybridisation with the noble kinds. All other wild and more resistant forms which have been tried as "fortifiers" in the crossings with noble cane, have up to now given hybrids of less value than those which are derived from this single wild kassoer plant. It was one wild plant which has opened the road for the rapid progress of the Java sugar industry in the last **25** years.

The clones from Java have been introduced into many other sugar-producing

countries and have there saved the industry, threatened by diseases. They have been used all over the world also for further successful crossings. Another famous series of clones has been bred in Coimbatore (India) where, in a way analogous to that used in Java, a set of new clones has been obtained by crossing resistant wild forms or low yielding forms with high yielding cultivated kinds. They can be grown under the rigourous conditions of North India without irrigation and they give there so much more yield of sugar per ha that they to a large extent have replaced the older kinds (Hudson, 1937, p. 297). The improvement work is being energetically continued in this country. Venkataraman's crossings of sugar cane with very different species of plants, even with maize and bamboe, might be mentioned. Little is yet known on the direct results of this latter work for the sugar industry, but the value of the new idea of making crossings between far distant species of plants is not limited to the sugar cane industry; it may open new roads for hybridising work in other crops.

Summary

In summarising the work on breeding sugar cane in Java, four features are outstanding:

a) The phenomenal tenfold increase in the hectare yield of sugar in the course of a century, obtained partly by general improvement in the growing technique but for the greatest part by improvement of the planting material.

b) That from the start this improvement was aimed as well at increase of yield as at resistance against disease. In this last direction the goal was attained when the breeder succeeded in crossing a very resistant wild form with the noble high yielding canes without considerable reduction of the hectare yield.

c) That the latter success was obtained by repeatedly back-crossing the hybrids with the noble forms till a point was reached where just a sufficient measure of the resistance complex was kept in the combination, while the yield-complex was increased to its possible maximum.

d) That with this hybridising work one single plant, Krüger's wild kassoer, found by chance, has proved of exceptional value, so that all superior clones introduced since 1927 contain some " blood " of it.

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The Tobacco Industry in Australia

Australia requires about 33,000,000 pounds of flue-cured tobacco annually and produces only 4,000,000 pounds, most of the balance being imported from the U.S.A. Production could be increased if water for irrigation were available during the "dry" season in the north-eastern coastal districts. The manufacturing industry is capable of meeting all requirements.

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Introduction

Tobacco has been grown in Australia for at least 120 years, but the quantity produced has always been small, the major proportion of local requirements being obtained either directly or indirectly from the U.S.A. At present about 88 percent of requirements is imported. Attempts to increase production, particularly during the last 30 years, have not met with much success despite support from Governmental and private agencies. To the casual observer this lack of success is remarkable because only a small area is required—the production from about 33,000 acres annually would meet the demand—in a continent of approximately 2,000,000,000 acres, situated in an apparently favourable climatic region. Yet such an area, either in one district or in several districts, where tobacco could be grown under conditions considered favourable in other countries, is not available. In recent years recognition of this disability has led to the successful introduction of production techniques involving modification of the environment to provide favourable growing conditions, and prospects for increased production have been enhanced.

Before 1900, tobacco manufactured in Australia was made almost entirely from Australian-grown leaf, but consumers preferred imported manufactured tobaccos made from American leaf. Subsequently tobacco leaf was imported from America, and a strong manufacturing industry capable of meeting full requirements has been established. The preferred origin of the leaf used, which is almost all of the flue-cured type, is the U.S.A., but in recent years some has been obtained from other countries.

Indigenous Species of *Nicotiana*

Prior to the establishment of white settlement in Australia, some of the indigenous species of *Nicotiana,* of which there are at least 15 (6), were highly valued by the Australian aboriginals for their narcotic properties and as a medium of exchange in intertribal barter. The product, known as "pituri", contained nicotine and was prepared mainly from *N. Gossei* Domin. and *N. excelsior* Black but also from leaves of *Duboisia Hopwoodii* F. Muell., another member of the Solanaceae. Leaves were dried over fires or in the sun, then mixed with wood ash from *Acacia* sp. and eventually consumed by chewing (4, 2). This practice was discontinued when products derived from *N. tabacum* L. became available and were used as part payment for services rendered, a procedure that is still followed by some employers of aboriginal labour. In addition to the indigenous species, *N. glauca* Grah., which was introduced about 100 years ago, is now

widespread, particularly in the ten- to 20-inch rainfall zone.

Nicotiana spp. are widely distributed throughout the temperate zone in the arid to semi-arid region which extends almost the full width of the Australian continent, yet nowhere do they occur in abundance. The aboriginals did not attempt cultivation of desirable species, nor did they engage in any form of agricultural activity other than the harvesting of naturally occurring products. This is in marked contrast with the stage of development reached in the Americas before the arrival of European settlers. Types of *Nicotiana* suitable for commercial production had been selected and cultivated for centuries (7), and two species, *N. rustica* L. and *N. tabacum*, are now grown in many countries. Of the Australian species, *N. debneyi* Domin. is of particular interest because of its resistance to blue mould disease (5, 3) caused by *Peronospora tabacina* Adam.

Historical

Tobacco was introduced to Australia soon after the establishment of the first settlement in 1788. In 1834, 158,000 lb. of leaf was grown in the colony of New South Wales. For the following 50 years production tended to increase. It was grown for local manufacture into tobacco, for export and for sheep wash. A further increase in production occurred during the period when supplies of leaf from the U.S.A. were interrupted by the American civil war, the peak being reached in 1888–89 when 7,000,000 lb. of leaf was produced from 6,641 acres. But by this time manufactured tobacco was again being imported in quantity, demand for locally grown leaf declined and production dropped to 500,000 lb. in 1903. For the following 28 years, production varied from 257,000 lb. to 3,714,000 lb. and acreages from 1,086 to 3,824. In 1932 a record production of 12,203,000 lb. was obtained from 20,266 acres. In 1933 the acreage increased by 13 percent, but yield declined by 22 percent. Since that time production has varied from 2,500,000 lb. to 7,000,000 lb. and acreage from 3,720 to 13,026.

Major Factors Affecting Production

These wide fluctuations in acreage and yield reflect the lack of stability in the industry brought about by both internal and external factors. The first major increase in production occurred as a result of the American civil war. Subsequently production declined to a low level, then increased following the World War of 1914–18. Again it dropped but reached a new high level in 1932 when economic depression forced an upward revision of customs tariffs. With the downward adjustment of tariffs in 1934, production tended toward stability at about 5,000,000 lb. but declined to 3,000,000 lb. during the last World War and has continued near this level despite circumstances favourable to greatly increased production.

Of the internal factors affecting stability, changes in fiscal policy, blue mould disease (*P. tabacina*), changes in consumer demand and unfavourable weather conditions have been of most importance. From about 1889 marked fluctuations in production have been brought about by the devastating effects of blue mould disease in seedbeds and fields. This disease can now be controlled in seedbeds (1), but field losses up to 90 percent can still occur, particularly in the State of Victoria. Consumer preference for bright tobacco rather than dark air-cured necessitated the adoption of production procedures that were unsuitable for tobacco grown on relatively fertile river-flat soils. Some districts went out of production, others continued on a restricted basis, and with the development, during the past 20 years, of more suitable areas there has been a cor-

responding improvement in the general position of the industry. Unfavourable weather, particularly inadequate or excessive rainfall, is likely to occur in all areas with consequent increased loss due to the effects of diseases and adverse growing conditions on yield and quality.

Growers early recognised the necessity for irrigation as a supplement to rainfall during the dry summer in the southern part of the continent and therefore utilised river flats adjacent to permanent streams. Following the discovery of gold in 1851 the area under tobacco increased, much of it being grown by Chinese who entered Australia to work on the goldfields. A share-farming system under which the grower provided labour and little else was established and has persisted in the older areas, but with the introduction of flue-curing the Chinese were replaced largely by growers of Italian stock. In the areas developed since 1930 the owner of the farm is usually the grower and therefore has a much better appreciation of the need for proper farming practices and for economic stability within the industry.

Effect of Weather Conditions on Production

Australia, as a whole, has a relatively dry climate. The arid interior with less than ten inches per annum occupies about 37 percent of the continent, while only 15 percent, much of it mountainous, has an average annual rainfall of more than 30 inches. The northern part has two well-defined seasons, the wet and the dry, January, February and March being the wet months in the areas producing tobacco. The southern part is in the winter rainfall zone. In the south-west of Western Australia almost all the rain falls during the period May to October, and in Victoria the summer rainfall is low. Thus under natural rainfall tobacco must be grown in the hot wet season in the north and in the hot dry season in the south. In the intermediate region rainfall is inadequate for tobacco-growing. Even where the mean annual rainfall during the growing season appears adequate it is unreliable both as to total amount and to time of occurrence.

Under these conditions growers in the southern half of the continent resorted to irrigation to supplement rainfall, but when flue-cured tobacco was required, the soils generally used for the production of air-cured tobacco were found to be unsuitable for bright tobacco.

Production Areas

About 1930 the results of an Australian-wide quest for more suitable areas led to the establishment of tobacco-growing in North Queensland and at Manjimup in the south-west of Western Australia under natural conditions. Despite the almost rainless growing season in Western Australia, good tobacco can be grown because the crop is produced on soils kept moist by the movement of seepage water from surrounding areas. Where irrigation is available other soils can be used. Atmospheric humidity is relatively high, but by comparison with flue-cured areas in the U.S.A. the mean temperature is low. Seasonal conditions from year to year are reasonably stable, and production, at present about 650,000 lb. from 660 acres, is tending in increase.

In North Queensland unreliability and erratic distribution of the monsoonal rainfall led to physiological disorders, and diseases and insect pests further reduced yields to 500 lb. per acre or less. With the introduction of production under irrigation during the latter part of the dry season, September to December inclusive, most of these difficulties were avoided and yield per acre increased by 100 percent. Moreover, such yields could be expected each year. Under such conditions increased production in areas of the Queensland coastal districts where water for irrigation is

TABLE I

WEATHER DATA—TOBACCO-GROWING AREAS IN AUSTRALIA

In all areas rainfall is unreliable in amount and time of occurrence.

Area and growing season	Map reference	Temperature °F. Monthly range of means			Rainfall (inches)		Relative humidity	Remarks
		Maximum	Minimum	Mean	Mean monthly range	Total		
North Queensland								
December-March	A	85–89	69–73	78–81	4.0–9.0	26	Satisfactory	High mean minimum temperatures. Rainfall very unreliable.
Sept.-December	B	83–89	61–72	71–81	0.2–4.0	6	"	Irrigation essential. Rainfall not important.
Southern Q'ld.								
November-March	C	90–93	64–68	77–80	2.5–3.0	14	Low (32–39%) (3 P.M.)	Irrigation essential. High maximum temperatures. Low degree of cloudiness.
Victoria								
November-March	D	77–87	46–54	62–71	1.7–2.4	10	Low (31–41%) (3 P.M.)	Irrigation essential. Wide variations in temperature and humidity.
West. Australia								
November-March	E	71–80	49–54	60–67	0.8–1.5	5.0	Satisfactory	Cool climate. Soils kept moist by seepage. Rainfall not important.

Source of data—Area A from unofficial records, others from Commonwealth Bureau of Meteorology.

available can be expected. Nevertheless, a rapid immediate increase in acreage is not possible because of present limited water storages. In this region the months of May to November inclusive are almost rainless, and the short coastal streams are reduced to a series of water holes. During the months of September to December inclusive, when necessary tobacco production continued on the lighter soil types. This district is hot and dry, and irrigation is essential. The present area of about 900 acres, from which 900,000 lb. of leaf is obtained cannot be increased to any extent until water storages are built. The Ovens Valley district of north-east Victoria is another area that has grown to-

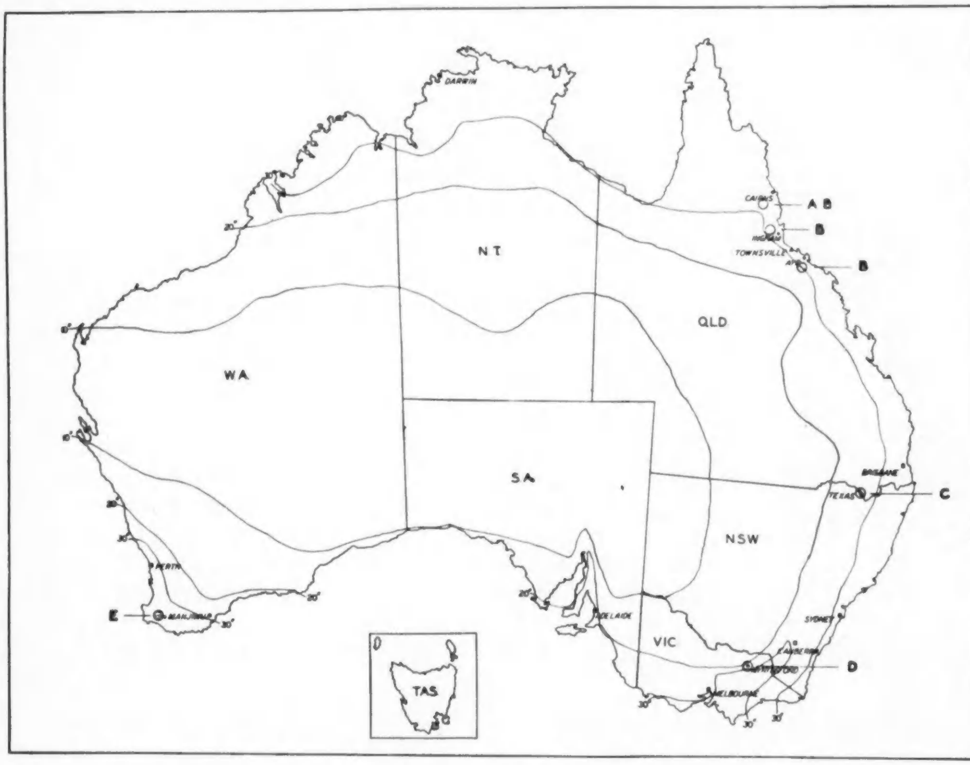

FIG. 1. Australia, showing tobacco-growing areas A to E (reference Table I) and isohyets of 10, 20, and 30 inches mean annual rainfall.

the crop is grown, water supplies are at their lowest; consequently only a limited increase in acreage can be expected pending construction of large water storages. Present production is about 1,600,000 lb. from 1,800 acres, part being grown under natural rainfall.

Air-cured tobacco has been grown in the Queensland-New South Wales border district in the vicinity of Texas for many years, and when flue-curing was

bacco for many years, but production is now restricted to the lighter soil types. Water for irrigation is available, but production is tending to decline because of the effects of unreliable weather conditions, the present expectation being about 650,000 lb. of leaf from 800 acres.

These four areas, separated by distances of 700 to 2,000 miles, at present produce a total of about 4,000,000 lb. of leaf from 4,200 acres. Each area has

different weather conditions, soils and cultural problems, and each produces a different type of flue-cured tobacco. The range of latitude extends from 17° S., elevation 1,300 feet, to 37° S., and longitude from 115° E. to 152° E. This wide dispersion of producing districts, brought about by the need for taking advantage of favourable conditions in any locality, has necessitated dispersion of effort by all associated with the industry, thereby adding to the difficulties of growers, manufacturers, and research and extension services.

TABLE II

ACREAGE, YIELD PER ACRE AND PRODUCTION OF TOBACCO IN AUSTRALIA BY CROP YEARS—AVERAGES 1927–46, ANNUAL 1947–50

Crop year	Acreage	Yield per acre	Production
	acres	*pounds*	*1000 pounds*
1927–31	2,533	656	1,662
1932–36	15,336	452	6,929
1937–41	9,343	553	5,169
1942–46	6,270	701	4,398
1947	4,492	889	3,994
1948	3,843	646	2,484
1949	3,720	918	3,416
1950	4,561	906	4,133

From Production Bulletins—Commonwealth Bureau of Census and Statistics, Canberra, A.C.T.

Experiment Work

For more than 50 years agricultural departments in the States concerned have employed advisers, some of them from the U.S.A., on tobacco culture. The Federal Government, instituted 50 years ago, did not take an active interest in production until 1928 when an organization known as the Australian Tobacco Investigation was established to undertake research and experiment work. In 1934 the Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.) continued with the work on diseases and leaf quality, while the States, with financial assistance from the Federal Government, extended field experiment investigations and advisory services. This work was discontinued for a period of approximately five years during the recent war, and on resumption the C.S.I.R.O. undertook investigations on tobacco grown under irrigation, on varieties, diseases, disease resistance and chemical composition. State experiment stations have been established in the Mareeba and Ayr districts of Queensland, at Myrtleford in Victoria and at Manjimup, W. A. At these stations and elsewhere, fertiliser requirements, varieties, rotation crops, irrigation procedures, etc., are under investigation.

The change from air to flue-cured tobacco, and consequent transfer of production to new areas, together with the effect of wide differences in weather conditions from season to season has meant that relatively little of the information gained from experiment work during the last 50 years in now applicable. Since 1930 the States have been concerned mainly with the re-establishment of production in areas capable of producing leaf of the required quality, while the C.S.I.R.O. has made most progress in the study of diseases. Now that production has been established on a sounder basis, relatively rapid advances in knowledge can be expected as a result of experiments in progress.

Marketing and Manufacture of Tobacco

The leaf is usually sorted on the farm, tied into hands and submitted for sale in hessian bales weighing up to 200 lb. Several forms of marketing have been tried, but none has proved completely satisfactory. For many years buyers visited the farms and purchased direct from the grower. Later, selling by auction was introduced, the baled leaf being sent to a capital city for inspection prior to the auction. Under wartime marketing regu-

lations values were determined according to a fixed schedule and the leaf allotted to manufacturers. At present most of the leaf is sold by auction, subject to the price offered being considered reasonable by representatives of growers' organisations. Most of the leaf is transported 200 miles to the selling floor, then up to 2,000 miles to tobacco factories in Melbourne and Sydney before being re-ordered, and under these conditions both growers and manufacturers experience difficulty in maintaining the leaf in good condition for the period of eight months that may elapse betwen harvest and re-packing for ageing.

The manufacturing industry established by small companies during the last century used Australian-grown leaf to make dark plug tobaccos, and when lighter tobaccos came into favour the demand for the product declined. In 1896, 60 percent of the tobacco consumed in Australia was imported manufactured tobacco, and to meet the demand for lighter tobaccos, Australian manufacturers increased the proportion of imported leaf in their products. About 1904 several companies merged to form The British-Australasian Tobacco Company which is now one of the three leading industrial organisations in Australia. This Company helped to maintain local production but preferred imported flue-cured leaf and has for many years manufactured 80–90 percent of the total requirements of Australia. The manufacturing potential in Australia is adequate for all demands, provided suitable leaf can be imported, and this, together with high customs duties on manufactured tobacco (A37s. or $4.14 per pound for cigarettes), has provided an assured local market.

TABLE III

AUSTRALIAN IMPORTS OF TOBACCO, NET REVENUE AND QUANTITY OF LEAF HELD IN BOND—AVERAGES 1931-32 TO 1945-46, ANNUAL 1946-47 TO 1948-49

Year	Imports		Average import price unmanufactured tobacco	Net revenue		Quantity in bond unmanufactured at 30th June
	Unstemmed leaf	Manufactured		Customs	Excise	
	1000 lb.	*1000 lb.*	*pence A.*	*1000 £ A.*	*1000 £ A.*	*1000 lb.*
1931-32 to 35-36	15,592	101	16.6	2,805	4,604	19,262
1936-37 to 40-41	20,623	693	19.8	3,390	6,307	27,503
1941-42 to 45-46	23,196	548	30.0	5,114	15,523	22,947
1946-47	19,912	949	45.0	7,791	19,343	27,516
1947-48	30,951	3,386	44.0	10,807	19,717	28,406
1948-49	23,545	7,358	52.0	14,612	19,180	26,761

From Oversea Trade Bulletins, Commonwealth Bureau of Census & Statistics, Canberra, A.C.T.

About 98 percent of all leaf used is of the flue-cured type, approximately one-third being consumed as cigarettes, one fifteenth as pipe tobacco and the remainder as cut tobacco suitable for use in hand-rolled cigarettes. The high consumption of "roll-your-own" tobacco reflects, in part, the smokers' preference but is mainly due to the higher cost of factory-made cigarettes brought about by high excise duties. Number of cigarettes per pound varies from 415 to 500, the average being about 460. The quantity of factory-made cigarettes consumed

is increasing at a greater rate than consumption of other forms, while the total quantity of cigars, snuff and chewing tobaccos form an insignificant proportion of total consumption. Statistical information on leaf used, tobacco produced and revenue collections is given in Tables III and IV. Most of the revenue from import duties comes from unstemmed leaf for manufacture into tobacco—A5s. ($.56) per lb., and from similar leaf for use in cigarettes—A7s.2d. ($.80) per lb. Additional revenue is obtained from excise duties, the more important being A14s.5d. ($1.61) per lb. on manufactured tobacco and A25s.10d. ($2.89) on factory-made cigarettes. Total revenue from tobacco is approximately A£1 ($2.24) for every pound of tobacco consumed, to which must be added an estimated 1s.3d. ($0.14)) for revenue collected on cigarette papers, matches and smokers requisites.

Under the protection given by tariffs, the manufacturing industry expanded to meet full requirements, but local production of leaf was not affected to any extent. The price paid for Australian-grown leaf remained lower than that for imported leaf, inclusive of import duty, because it was considered inferior in quality.

TABLE IV

AUSTRALIAN MANUFACTURE AND CONSUMPTION OF TOBACCO—AVERAGES 1931–32 TO 1945–46, ANNUAL 1946–47 TO 1948–49

Year	Stemmed leaf used in manufacture	Production		Consumption	
		Tobacco	Cigarettes	Total	Per head
	1000 lb.	*1000 lb.*	*1000 lb.*	*1000 lb.*	*pounds*
1931–32 to 35–36	17,122	14,666	4,650	18,933	2.845
1936–37 to 40–41	20,593	16,248	6,761	22,696	3.279
1941–42 to 45–46	23,707	18,074	8,709	24,931	3.427
1946–47	27,052	20,179	10,082	29,109	3.881
1947–48	26,599	19,715	10,147	32,002	4.150
1948–49	25,859	19,256	9,701	34,005	4.360

From Production Bulletins, Commonwealth Bureau of Census and Statistics, Canberra, A.C.T.

Summary

In Australia tobacco is a minor agricultural crop mainly because of unfavourable climatic conditions and consequent lack of stability. Irrigation as a supplement to rainfall has helped to maintain production in areas where the summer rainfall is low and the soil suitable. During the last few years successful results have been obtained under irrigation during the " dry " season in north-eastern coastal regions. Under present conditions production is expected to increase by at least 50 percent to six million pounds of leaf, the immediate factors retarding expansion being shortages in building materials, equipment and manpower. A further substantial increase in production to provide the major proportion of requirements, at present about 33 million pounds of leaf annually, could occur if water for irrigation were provided in suitable areas.

Almost all tobacco consumed is of the flue-cured type, about 85 percent of requirements being imported as leaf, mostly from the U.S.A., and manufactured in Australia. Major products are cut tobacco suitable for hand-rolled cigarettes, machine-made cigarettes and pipe tobaccos. Tobacco is an important source of Government revenue, import

and excise duties amounting to about A21s.3d. ($2.38) per pound of tobacco consumed.

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Utilization Abstract

Drugs of Microbial Origin. Many molds among the true fungi have been shown to produce powerful antibiotic substances, but so far penicillin from *Penicillium notatum* and *P. chrysogenum* " is the only antibiotic derived from the higher fungi that has attained the status of an officially recognized and useful drug ". Professor Fleming's original strain of *P. notatum* was used in all early studies in both England and the United States with the bottle technique, but other strains have been found more suitable for the present submerged production. By selection of natural variants and the production of mutants of *P. chrysogenum* through exposure of spores to X-ray and ultraviolet radiation, production of penicillin has been increased from 75–100 units per milliliter to 900–1,000 units in present day manufacture in this country and abroad. Of the four types of penicillin—F, G, K and X—known to be produced by these two species of *Penicillium,* only penicillin G is now manufactured, being produced usually as the potassium or sodium salt in a highly purified, colorless, crystalline product. Production rose from less than 21 billion units in 1943 to more than 200 trillion units in 1950.

" From the Actinomycetes, a group of micro-organisms somewhat intermediate between the filamentous fungi and the bacteria, four important drugs of microbial origin are now obtained—streptomycin, chloromycetin, aureomycin, and terramycin ". Commercial production of streptomycin is achieved by growing a high yielding culture of *Streptomyces griseus* in a medium of meat or vegetable protein, minerals and a carbohydrate, such as dextrose. A valuable by-product of this fermentation is vitamin B_{12}, effective in treating pernicious and other forms of anemia. By January, 1950, commercial production of streptomycin had risen to about eight and one-half tons per month.

Chloromycetin, originally isolated from cultures of *Streptomyces venezuelae,* is now produced on a large scale, both synthetically and by fermentation. Aureomycin is now being produced in quantity from the actinomycete *Streptomyces aureofaciens* by one large pharmaceutical manufacturer. Neomycin, produced by *Streptomyces fradiae,* is still in the experimental stage, and terramycin from *S. rimosus* is the most recently discovered of the group.

Among the bacteria, the common spore-bearing and soil-inhabiting *Bacillus subtilis* has yielded 11 different antibiotic substances, the most promising of which are bacitracin and subtilin. (K. B. Raper and R. C. Benedict, *U. S. Dept. Agr., Yearbook 1950–1951*).

Hops—*Their Botany, History, Production and Utilization*

The female cone-like inflorescences of this vine are composed of scales covered with glandular hairs which produce, among other compounds, the bitter principle which has long been an indispensable ingredient in the brewing of beer. These large-scale catkins have been used also in medicine because of their sedative and soporific properties, and as a tonic.

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History

Various parts of the hop plant have been used by man in the past and are still utilized. Pliny referred to this plant in his Natural History as *lupulus salictarius,* a plant which at his time served as an appetizer and as a salad green. The Greeks used hops only as a salad plant, and young hop shoots are still eaten in parts of Central Europe as a salad vegetable. In the past, many ills of man were treated by physicians with prescriptions of hops to be consumed green or in various liquid concoctions, of which hops were the principal ingredient. Hops were reputed to cure a wide range of maladies; they were supposed to free the blood of all " impurities, tumors and flatulence ", to cure the itch and other skin diseases, and to " relieve the liver and spleen ". Recently the antibacterial agents of hops, humulon and lupulon, have been found to inhibit growth of the tuberculosis bacterium (**8**). Fibers from hop stems have been used in the manufacture of twine and a textile fabric resembling linen in Sweden; an extract of hops has been used as a hair rinse for brunettes in Russia; and brewers' spent hops have been used as fodder and as the basis of manures in most countries producing beer. Although hops have been used for many and varied purposes, their principal use today is in the brewing of beer.

The art of brewing and the pleasure of drinking beer date back more than **5,500** years. In **1935** an expedition of archaeologists from the Museum of the University of Pennsylvania and the American Schools of Oriental Research, who were excavating in Mesopotamia, found a seal baked in pottery which showed two brewery workers using long poles to stir the contents of a brewery vat. The date of this artifact was estimated as the 37th Century B.C. Fifty-three hundred years later a publication in **1622**, " A Relation, or Journal, of the Beginning and Proceedings of the English Plantation Settled at Plymouth, in New England ", indicates that shortage of the beer supply on the Mayflower was partly responsible for the landing of the Pilgrims at Plymouth: " For we would not now take time for further search or consideration: our victuals being much spent, especially our beer . . . " (**10**).

The beer of the Ancients was consumed for much the same reasons modern beer is consumed today. The principles of brewing are essentially the

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same today as they were at the beginnings of civilization. However, ancient beer must have tasted different from modern beer, since different herbs were added for bitterness. Moreover, ancient beer did not keep well, whereas modern beer, as a result of pasteurization and the preservative value of hops, can be kept for long periods of time.

There is no evidence that any beer produced before the 8th Century A.D. contained hops. Beer was undoubtedly hopped before that time, but the earliest records on the hop as a cultivated plant are dated 760 A.D. This report is a recording of a gift in which King Pépin le Bref, the father of Charlemagne, donated homularias (hop gardens) to the Monastery of St. Denis (6). In the first years of the 9th Century the Abbot of St. Germain-des-Prés issued the Polyptych of Irmino which mentions the payment of hop-dues.

During the Middle Ages many monasteries became famous for their hopped beers. Beer was the chief drink for breakfast, dinner and supper at that time, and the beer trade developed greatly as the towns grew. By 1320–30 A.D. hopped beer was in general favor in Germany. Later in the 14th Century the hop crop became important in Flanders, and Flemish and northern German towns became wealthy through sale of their hopped beer. Ghent was the most famous town in Flanders, and Eimbeck the most famous in Germany.

Hops were not introduced into England until toward the close of the 15th Century. Henry VII and Henry VIII of England liked beer without hops and therefore prohibited their use. In Sweden tastes were quite the opposite; an ordinance in 1440 required every farmer to grow 40 poles of hops. In Bohemia the Emperor Charles IV personally selected the spot most suitable for hop growing.

Hop growing in North America began in New Netherlands as early as 1629 and in Virginia in 1648. It did not become important, however, until about 1800, and by 1849 the New England states and New York produced nearly 1,500,000 pounds. After the Civil War the industry developed in Wisconsin. Growing of hops on the Pacific Coast was started between 1859 and 1869, and by 1909 this region had become the leading hop-producing area in the United States.

TABLE I[2]

PRINCIPAL HOP-PRODUCING COUNTRIES AND REGIONS

United States:
- Willamette Valley and Grant's Pass District in Oregon;
- Yakima Valley and Western Washington Districts in Washington State;
- Sonoma County, Mendocino County and Sacramento Valley in California; also
- Idaho and New York State.

England:
- Kent, Sussex, Hereford, Worcester, Hants, Surrey.

Czechoslovakia:
- Saaz, Auscha, Raudnitz, Dauba.

Germany:
- Hallertau, Spalt, Hersbruck, Tettnang, Wuerttenberg, Baden.

Yugoslavia:
- Wojwodina, Slovenia.

France:
- Alsace, Burgundy and Lorraine, northern France.

Belgium:
- Alost, Poperinghe.

Poland:
- Wolhynia, Congresspoland, Galicia, Posen.

Australia and New Zealand.

Russia.

Canada.

Botany

The common hop (*Humulus lupulus* L.) and a native American species (*H. americanus* Nutt.) include all commercial hop varieties. These species, which differ in the shape of their leaves and stipules, belong to the family Moraceae.

[2] From: The Practical Brewer, Vogel, E. H., Jr., *et al.;* published by The Master Brewers Association of America, 1946.

The hop plant is a perennial herbaceous vine. The root system is extensive, with many of the roots penetrating to great depths. The horizontal roots give rise to enormous numbers of fine rootlets.

There are two types of stem in the hop plant: perennial underground rhizomes and annual herbaceous " bines " above ground. The latter develop from buds on the rhizomes each year. The main stems carry opposite lateral branches which attain their greatest length around the middle of the stem. These lateral branches bear the pistillate inflorescences. The aerial stems are incapable of supporting their own weight and twine in a clockwise direction around any available support. Growth in length is greatest and the internodes longest when the support is vertical. If the support is inclined at a slight angle, growth continues for a longer period and is more even. If the support is placed at a 45 or 60 degree angle, climbing is checked because the tips fall away from the support.

The hop is dioecious, although occasionally a monoecious plant may be found. Plants producing male or female flowers, or both types, in any one year tend to be similar in other years; but occasional exceptions occur in which monoecious plants become dioecious, and formerly dioecious plants become monoecious.

The staminate inflorescences are much branched cymose panicles, two to six inches long, developing in the leaf axils of either the main or the lateral shoots.

The pistillate inflorescences are spike-like in appearance and are born in leaf axils of either the main stem or more frequently the lateral branches. They are called " burrs ", " strobiles " or " cones ". These constitute the commercial hop. The main axis of the cone is thick, covered with fine downy hair, and carries a series of opposite and alternate short lateral axes. At the base of each lateral is a pair of bracts. Each lateral axis is a cymose branch carrying four pistillate flowers. Each of these flowers is subtended by a bracteole.

At pollination the bracts are small and only the basal ones are visible. The stigmas are conspicuous and are pollinated by wind drifted pollen from the staminate plants. After pollination the stigmas fall off and the bracteoles enlarge, the seed starts to develop, and in a short time the cone takes on a characteristic " fir-cone " appearance. If pollination is prevented, no seed is set and the bracteoles remain comparatively small (1).

On the cup of the perianth, on the outer and lower surfaces of the bracteoles, and to a lesser extent on the bases of the stipular bracts, there occur yellow pollen-like structures constituting the " hop-meal " or " lupulin ". In the young hop they are bright golden and transparent; in the ripe hop they are citron yellow and opaque. The commercial value of hops depends on the amount and quality of this lupulin.

Each such granule is the product of a glandular hair which develops from a single epidermal cell in the perianth or bract. Before pollination each gland consists of a short stalk, one to three cells long, and a terminal cup. This cup is composed of a single layer of cells with a thick cuticle. During elongation of the bracts, each cell of the cup commences to produce an internal secretion which accumulates beneath the cuticle. As this secretion increases, the cuticle is slowly raised until it bulges into a dome-shaped mass. For the most part, the usable constituents of the hop are contained in this secretion of the glands. These substances will be discussed in the section on utilization.

Late Clusters is the most widely grown American hop. This variety may have originated as a hybrid between an im-

TABLE II

CONSTITUENTS OF KILN-DRIED HOPS[3]

	Percent		Percent
Moisture	9–13	Pectins	9–11
Resins	10–20	Ash	6–10
Oil	0.2–0.5	Nitrogen	2–4
Tannin	2–5	Glucose, Fructose	2–4

ported English hop and an American hop. It is a good yielder with a high soft resin content, but is quite susceptible to downy mildew, plant lice and red spider. Early Clusters, an earlier maturing selection from Late Clusters, is also susceptible to downy mildew. Fuggles, an introduced English hop, is resistant to downy mildew, but its yields are much lower than those of Late or Early Clusters; also, its soft resin content is comparatively low. These three varieties are the principal ones grown in the United States.

Environment

The quality of hops is markedly influenced by environmental conditions. The plant does best under temperature conditions without sharp and often repeated fluctuations. The plant develops more satisfactorily when the temperature rises slowly and constantly from early spring to the middle of summer and then gradually and uniformly diminishes. Ideal moisture conditions are provided when the plant has abundant moisture accumulated during the winter to draw on. After growth starts, cold spring rains are harmful. The latter part of the summer should be dry; however, protracted dry periods or hot dry winds have an unfavorable effect on the normal development of the vines. Excessive rainfall in the harvest months, late August and September, frequently results in heavy damage from insects and diseases.

[3] From: Brewing Science and Practice, Vol. I, Hind, H. L.

The hop is a deep-rooted plant requiring a deep well-drained soil. In general, alluvial soils, or deep sandy or gravelly loam soils, are most desirable. Because of differences in the amount of rainfall and sunshine, and in the force of prevailing winds, soils suitable for hop culture in one region may be unsuitable in another. Heavy wet soil or stiff clay soils are avoided in planting hops. In Europe and to a lesser extent in the United States, leguminous green manure crops are planted immediately before hop harvest. The green manure crop is plowed under early the following spring. Some growers use a mixture of legumes and winter cereals, or winter cereals alone, for a cover crop.

Growing and Handling

Hops are usually propagated from rhizome cuttings. Seed planting is impractical because the seedlings' lack of uniformity varies their time of ripening. The cuttings are commonly referred to as " root cuttings " or " roots ". The numerous rhizomes sent out by the plant just below ground level are usually removed during the pruning operation in spring. The runners, which are approximately one-half inch in diameter, are cut into pieces six to eight inches long, each piece bearing at least two pairs of buds or " eyes ". These are used to produce new plants. In some sections of the Pacific Coast a crop may be obtained from cuttings planted in the spring, but generally a full crop is not harvested until the second or third year.

The common practice is to plant the cuttings in hills in rows. In the older hop yards, the hills are six to seven feet apart. In more recently established yards the plants are set eight feet apart. The methods of cultivating the hop yards necessitate straight rows. Two or four cuttings are usually set in each hill. The setting of extra cuttings is a precaution against losses due to vacant

hills. The upper ends of the cuttings are placed about seven inches below the surface of the soil. As the cuttings grow, the holes are filled up until level with the ground, or the holes may be covered immediately after planting. Old hop plants produce a superior quality of hops, although they bear scantily. Seven years is usually the limit of profitable cultivation.

Excess shoots and old vines are removed by pruning a short depth below the soil surface to suppress the formation of undesirable runners. Working over the ground incident to pruning is an important part of cultivation. A common practice is to draw four or five furrows with a small plow on each side of the row, turning the earth away from the hills. The yard is then cross plowed in a similar manner, leaving each hill a small undisturbed area (4).

There are two systems of hop culture, the plants being trained on poles or on wires. In the pole system a pole about 20 feet long is set in the ground beside each plant, and two vines are trained up on it, held in position by twine. This system has been largely discarded in favor of the trellis system in both Europe and the United States. The wire trellis is constructed in many ways, but all of these can be included in the two general classes, the high and the low trellis. The low trellis generally is set up on poles or stakes about eight feet long at each hill. Wires are run over the tops of the poles for the full length of the yard each way, crossing at right angles. The vines are led up the poles and then supported by the wires. The hop vine will not follow a horizontal support; therefore it must be trained by hand around the horizontal wires of the trellis.

The high trellis is the most widely used. Fertility of the soil and wind damage are the limiting factors of the trellis height which ranges from 12 to 20 feet. This is a permanent structure which allows easy access to any part of the yard. Also, the hops receive more uniform exposure to light and are better developed; cultivation is not hampered so much by drooping arms as in the low trellis system; and the hop can be easily sprayed, even at picking time when the worst attacks of insects usually occur. Training in the high trellis system requires the use of training sleds or carts.

A typical high trellis system consists of setting posts at every sixth or seventh hill each way throughout the yard. Wires are strung at right angles to each other at or near the top of these posts. Twine is used to support the vines until they reach the wires.

When the vines are about two feet long, training is begun. The desirable vines are selected in each hill and the remainder are cut off. In light producing areas the first vines are trained to provide them with as long a growing season as possible. In heavier producing areas the second or later " crop " of vines are chosen. Here sufficiently vigorous vine growth is obtained in a minimum period of time. As soon as the desired number of vines have been trained, it is customary to remove the lowest pair of leaves. This is done to prevent spread of downy mildew. This practice is known as " stripping ", but if the vines are stripped too high, a " top crop " results and the yield is reduced. All suckers are removed from around the bases of the plants. Both stripping and suckering are primarily employed to force the growth of the selected shoots (4).

Hops should be picked when fully mature, the time of which varies with locality, variety and seasonal conditions, but is usually fairly constant from season to season in any one location. The earliest ripening hops are ready for picking in early August in the United States. Ripeness largely determines quality. When the acreage is large, growers begin picking the crop before it is ripe because

FIG. 1 (*Upper*). A low trellis hop yard in western Washington.

FIG. 2 (*Lower*). A high trellis yard in the Sacramento area of California. (*Photos by courtesy of U. S. Bureau of Plant Industry*).

of fear of loss by over-ripeness or damage from insects and diseases. Unripe or immature hops are deep green, soft and pliable, and lack resiliency or elasticity. The cones are smaller and contain more moisture. The lupulin in unripe hops is not fully developed and contains less resins and essential oil. Ripe or fully matured hops have a full agreeable aroma and contain their maximum content of humulon and lupulon. They are usually bright yellowish-green, sticky, crisp or papery to the touch, and noticeably resilient.

In recent years, due to labor shortages, use of both portable and stationary hop-picking machines has increased in the United States. For example, approximately 40% of the hop crop in Oregon is machine picked (9). The lateral cone-bearing branches are fed to the picking machines by rotary drums, and continuous belts deposit the cones in baskets or bags. It has been found that machine picked hops generally contain less leaves and stems than those which are hand picked.

Drying

The next step in preparation of hops for market is the drying process. Freshly picked hops contain from 65% to 80% moisture, depending on the variety and the degree of ripeness. This moisture must be reduced to approximately 12% or heating will take place. Heating causes a brownish color to develop in the bracts and a loss in essential oil through volatilization.

It is possible to dry hops by forcing a large volume of air at relatively low temperatures through them. In arid regions hops are dried by forcing large volumes of dry air through them at temperatures of 110° to 115° F. (12). In more humid sections the air is heated to 145° to 150°. If temperatures above 165° F. are used, the hops can be dried in ten to 12 hours. Under such extreme conditions, however, they are apt to become fluffy, shatter easily and have a scorched aroma, making them less desirable to the trade.

Hops are dried in kilns. There are two types in general use: the natural-draft stove kiln, in which a stove or furnace placed under the floor heats the hops; and the forced-draft kiln, in which a current of heated air is drawn through or forced in through the hops by a fan. There is no definite rule for determining when hops are sufficiently dried. In general, drying should be continued until the stems or cones are shriveled but are still soft and pliable.

Formerly sulfuring was almost a universal practice which gave the hops a uniform golden appearance. Sulfur was burned beneath the kiln floor at a rate of one to four pounds for 100 pounds of undried hops. Besides a bleaching effect it was thought that drying was accelerated. Dealers are guided as much by the color of the hops as by any other criterion, and at one time unsulfured hops were graded inferior, while sulfured hops from the same field were graded choice. But tastes in color have changed and now green hops are preferred. Whether sulfuring had any real value for the purposes mentioned, other than for bleaching, is problematical (4).

After the hops have been dried they are cooled to equalize the moisture content, since each batch from the kiln does not have the same percent of moisture. This curing or sweating process lasts ten days to two weeks. After being placed in the cooler, the hops are handled as little as possible to prevent breakage. In the curing process they become tough and pliable and acquire a finer aroma and better appearance.

After the moisture content of the hops is equalized to approximately 12% they are baled. The dimensions and cubic contents of commercial bales vary because of differences in dimensions of

baling presses, as well as in the pressures to which the hops are subjected. The bale for domestic use in the United States contains approximately 18 cubic feet of hops. In this type of bale, which weighs about 195 pounds net, the hops are compressed to approximately 11 pounds per cubic foot. For export the hops are compressed to as much as 20 to 24 pounds per cubic foot. Such hops are termed " recompressed ", since they are compressed from domestic bales. Hops are baled in jute bagging, 16 threads or less to the inch. About five running yards of bagging are used for each bale. This weighs from seven to ten pounds, and in selling, a five-pound deduction of weight is made in allowance for the weight of the bagging.

Hops undergo gradual changes in their constituents while in the bale, depending on the conditions of storage. Growers often hold baled hops in storage for considerable periods. Unless there is available cold storage space, with a temperature of 32°–33° F., and a relative humidity of less than 75%, the baled hops are usually subject to comparatively high temperatures which are detrimental to quality. Under such conditions the soft resins are partially oxidized to hard resins, and the essential oil is volatilized. Unless the hops are sold immediately or placed in cold storage, the grower will be forced to take a reduction in price because his hops will have been lowered in quality.

FIG. 3. Typical high trellis yard in the Willamette Valley of Oregon. Vine growth in late season just before harvest. (*Photo by courtesy of U. S. Bureau of Plant Industry*).

Diseases and Insects

The diseases of hops which are of the greatest economic importance are downy mildew, sooty mold, root rots, several virus diseases, powdery mildew and crown gall. Fungicidal dusts and sprays

are used to control the mildews. There are no effective controls for sooty mold, root rots or virus diseases. The only measures the grower can take are to plant healthy stock and exercise care in pruning and cultivation so the plants will be injured as little as possible.

Hops are subject to attack by a large number of insects and other pests. Among the more common insect pests are the hop aphid, the common red spider, hop-plant borer, hop butterfly, hop flea beetle and the western spotted cucumber beetle. The two most important pests responsible for serious annual losses in the United States are the hop aphid and the common red spider.

Aphids devitalize the plants by extracting sap from the leaves, and they excrete honey dew in which sooty mold develops. The most common insecticide used in combating hop aphids is nicotine sulfate, applied as a liquid spray or as a dust.

The common red spider injures the hop plant by withdrawing the sap from punctures in the lower leaf surfaces. The punctures become more numerous as feeding continues, and eventually the leaves shrivel and die. Late in the season the cones are attacked, and their color is changed to a reddish brown, rendering them unmarketable. Burning infested plants after harvest, suckering and stripping the vines are common practices of control. Most growers are forced to spray or dust several times during a season in order to hold these pests in check. Sulfur in some form is the standard control for the common red spider.

Utilization

The brewer uses hops for production of aroma and bitter flavor, and because they contain preservative substances. The most important of these active principles are the bitter acids humulon and lupulon, contained in the lupulin. In the process of brewing beer, hops are added to the wort (the mixture of fermentable extract from flaked cereals or raw grain, plus hot water) in the " copper ", a vessel in which the wort is boiled with the hops. Boiling sterilizes the wort, extracts from the hops the preservative substances which also give flavor and aroma to the beer, and coagulates and precipitates part of the proteins which, if left in, would gradually separate as haze in the beer. The wort is concentrated and the enzymes of the malt are destroyed in the boiling process.

The bitter acids humulon and lupulon are synthesized during growth of the hops. During ripening, drying and storage these acids are oxidized to resins. Humulon is converted by oxidation in part to alpha soft resin and in part to alpha hard resin. Lupulon is converted by oxidation in part to beta soft resin and in part to beta hard resin. The hard resins have little or no value in brewing.

Hop preservative substances prevent Gram-positive bacteria from growing in either the beer or the wort. Gram-negative bacteria and acetic bacteria are not affected by the hop resin antiseptic. Micrococci will not develop in hopped beer but may develop slowly in the wort. Lactic acid bacteria, *Lactobacillus* and *Streptococcus* are retarded by hop rates of as low as one half pound per barrel.

Until a few years ago it was taken for granted that all the resins dissolved in the " copper " more or less come through in the beer. However, Walker's (16) experiments show that only a small percent survives the boiling and fermentation processes and that the preservative value which finds its way into the beer is a small fraction of the original preservative value of the hops used. By utilizing the ratio of the percentage of reduction of acid formation by *Lactobacillus Bulgaricus* to the percentage concentration of antiseptic hop substances, a preservative value of 10 alpha was determined.

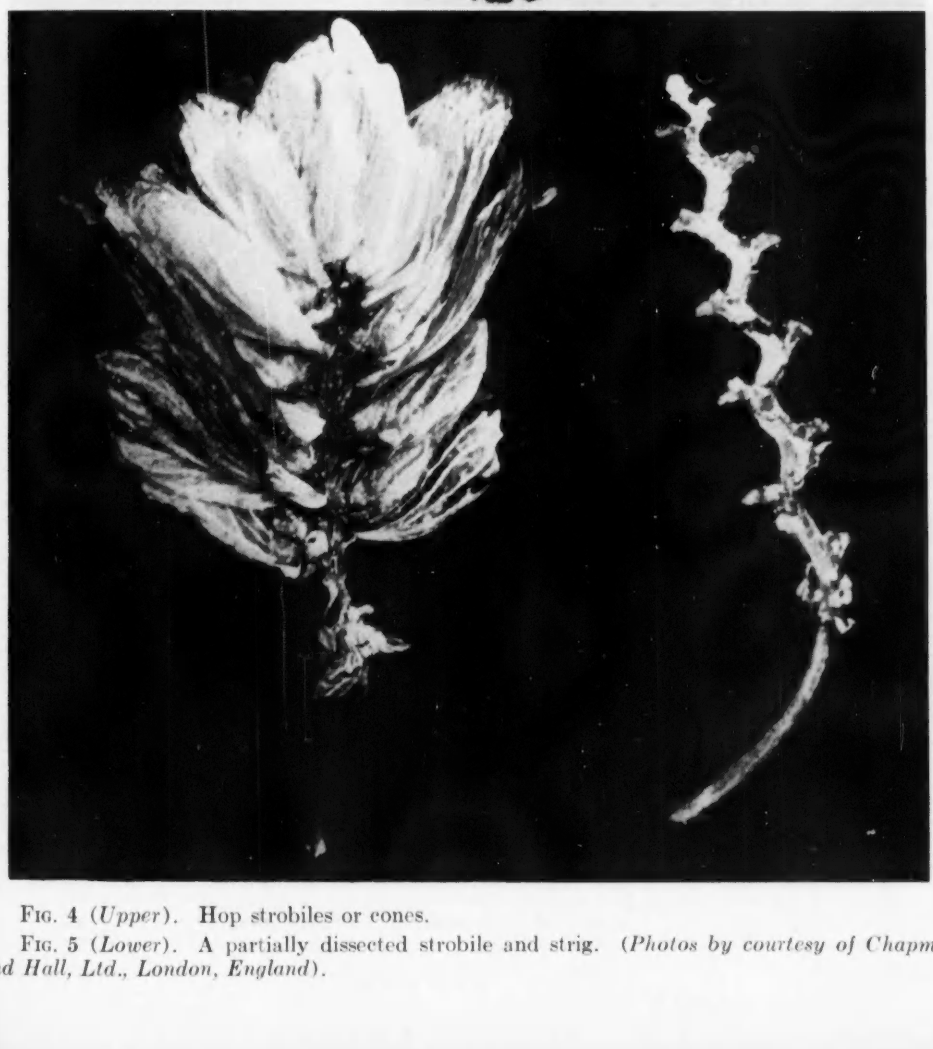

FIG. 4 (*Upper*). Hop strobiles or cones.

FIG. 5 (*Lower*). A partially dissected strobile and strig. (*Photos by courtesy of Chapman and Hall, Ltd., London, England*).

Alpha represents the percentage of humulon in the hop sample. This is an expression of the preservative power of hops, representing what is gotten out of the hop in brewing, rather than what the hop contains before its use in brewing.

It was found that after completion of the boiling and fermentation processes, all the preservative value of lupulon and its derivatives had been lost, while the remaining antiseptic material, derived from humulon, had a preservative value of only 10% to 20% of that of the quantity of humulon initially present before the hops were added to the wort. The use of the value 10 alpha by the brewer in selecting hops will be discussed later.

There is a definite limit to the solubility of hop resins in the " copper ", and apparently the limits are reached using hops with a 5% humulon content at the rate of 1.5 pounds per barrel. As far as preservative value goes, it is not economical to use higher rates (17).

Preservative value and bitterness are so intimately connected with the resins that usually it is assumed a pleasant bitterness will be associated with adequate stability in the beer. Since the resins are colloidal, the bitterness is more intense as they are dispersed, due to the increased surface effects on sensory nerves (3). The alpha soft resin conveys much more bitterness to the wort than beta soft resin. However, the alpha resins have been found to give no aroma, while the beta resins give a definitely pleasant aroma. The bitter of hops differs from all other vegetable bitters in its fugitive character. When the bitter liquid has left the palate, the bitter taste also disappears and does not continue to effect the palate as do other bitters (5).

The tannin content of hops varies and has little or no relationship to either quality or degree of ripeness. Amounts contained in English hops range from 1.7% to slightly over 3%, while Continental European and American hops often exceed 4%. Tannin is readily oxidized to an insoluble condensation product, phlobaphene, during boiling in the wort. Protein-phlobaphenes are insoluble and are precipitated during boiling. Protein-tannins are responsible for the haze in beer. The tannin compounds are soluble in hot wort, but on cooling they are precipitated and then redissolved when the wort is heated again. They are deposited with a fine sludge during cooling, but the precipitation is slow and incomplete. It continues during fermentation and storage and in finished beer, giving rise to haze.

The amount of nitrogen dissolved from hops in the " copper " is comparatively small, comprising 4% to 5% of the permanently soluble nitrogen in the wort. About 60% of this nitrogen is capable of assimilation by yeast, so that hops do improve the yeast feeding properties to a small extent, although it is doubtful that it is sufficient to have much practical significance.

The amount of essential oil contained in hops is small, varying from 0.2% to 0.5%. Humulene ($C_{15}H_{24}O_9$) and myrcene ($C_{10}H_{16}$) form 80% to 90% of the oil distilled from hops. Humulene accounts for approximately 50%, while myrcene accounts for 30% to 40% of the oil distilled from new hops. The essential oil of hops is completely volatilized for practical purposes in the boiling process. For this reason extracts of hop oil are added to the beer in the racks to increase the hop aroma. The oil is added at the rate of approximately one milliliter per ten barrels.

In order to increase aroma some beers are dry hopped. Two ounces to one pound of specially selected hops are placed in the casks previous to storing. The oil is only slightly soluble, so the hops must remain in contact with the beer for several weeks. The preservative value of dry hopped beer is increased

FIG. 6 (*Upper*). Bracts and bracteoles of a dried hop cone.

FIG. 7 (*Lower*). Base of a bracteole with lupulin. (*Photos by courtesy of Chapman and Hall, Ltd., London, England*).

slightly, and the cones prevent settlement of yeast into a hard deposit, thus facilitating subsequent cask washing.

It has been mentioned that hop rates over 1.5 pounds per barrel do not increase the preservative value. However, the aroma and bitterness imparted to the beer by the hops is as important as the antiseptic qualities. Therefore, hop rates of from 2.5 pounds to four pounds per barrel are customary in European beers. Each 31-gallon barrel of beer brewed in the United States utilizes only one-half to four-fifths of a pound of hops. American beers are pasteurized, and the hop rate does not have to be so high in regard to preservative value. American beers, however, are less bitter and their aromas less pronounced compared to European beers with high hop rates.

The brewer selects hops after judging a sample by hand examination; however, many brewers rely on the analysis of preservative value for their final decision on hop selection. The formula 10 alpha gives the brewer an insight into the preservative value and the aroma and bitterness he can get out of a sample of hops when the humulon content has been determined. A reliable estimate of the brewing value can usually be reached, however, by hand examination of the sample.

The brewer likes a whole hop and a sticky hop. When hops are broken up, there is danger that ruptured glands may lose their resinous contents. Good fresh samples of individual hops, rich in lupulin, stick together and slowly open out again when pressed tightly in the hand, although as a whole a properly dried sample is elastic and springy. The lupulin glands are examined with a hand lens. The indications of high quality lupulin are golden yellow glands with slightly wrinkled surfaces and oily contents which ooze out under pressure.

Most brewers show a decided preference for a hop with very few seeds. Seeds increase the weight of the hops, but they are of no value to the brewer. Hops containing a high percentage of seeds would be objectionable, since they can cause obstructions in refrigerator pans and cask taps. Growth of male plants is permitted in the United States and England, but premium prices are paid for seedless hops in these countries. In Continental Europe production of seed is prohibited by law, since they are held to impair the quality and flavor of beer.

The aroma of hops, an indication of essential oil content, is judged after rubbing some of the sample in the hand. The brewer is concerned in satisfying himself that the hops possess sufficient aroma of the right kind, and that they are free from objectionable odors, or odors which in his experience connote deterioration due to age or damp packing. Damp packing gives rise to a musty odor, while old hops acquire an odor somewhat like that of cheese.

Improvement and Breeding

In the United States the first concerted effort toward improvement of hops was begun in 1900 when roots of superior European varieties were imported by the Department of Agriculture. Yield tests showed, however, that these varieties did not produce enough to make their use profitable under American conditions. This is comparable with the results of corn trials in the United States where many varieties do well only within restricted localities.

In 1908 Stockberger outlined a comprehensive breeding program for hops in which he proposed a study of domestic varieties, selection of promising individuals and development of desirable types by hybridization. Work proceeded on this plan until 1916 when it was interrupted by World War I. Later the lack of funds and finally prohibition led to abandonment of the project.

The U.S.D.A. in 1930–31 made an extensive survey of plant material being grown in commercial yards in Oregon. As a result of this survey and of less comprehensive ones in California and Washington, vegetative selections were made. In addition, in 1931 importation of superior English and Continental varieties was resumed (14). Three varieties from Germany and one from Alsace were found to maintain a very high soft resin content, from 18% to 21%, over a period of six to eight successive seasons (11).

Improved varieties have been produced in Europe and the United States by vegetative selection, but the most promising method of varietal improvement is selection of superior plants from seed. The hop is one of the few cultivated plant species which is dioecious. Although seeded hops are discriminated against on the market, and male plants are unnecessary in producing commercial hops, seed production is necessary in breeding work.

Smith (14) has pointed out that the problem of breeding improved hops is analogous to the problem of increasing milk production in dairy cattle. Cone development is purely a female character, but genetically the male also contributes to the qualities of the hop. The only method of determining the value of the male's contribution to the characteristic being selected is by progeny testing.

Seed may be collected from a good female with the expectancy that some of the progeny will exceed the maternal plant in some characters. The male parent is unknown in such cases. Seed may be obtained also by artificial pollination. The results of such crosses allow selection in the F_1 generation for desirable plants and for judging the male parent. While the hop breeder is at a disadvantage in working with a crop that does not permit rapid inbreeding for fixation of genotype, he has a distinct advantage in dealing with the F_1 generation. If he obtains a desirable female plant in the F_1, his breeding work is finished. This rather unique situation is due to the possibility of vegetative propagation of the selected F_1 females and the fact that seeds are not desired in commercial hops.

The lapse of the entire hop improvement program in the United States in 1916 seriously retarded the breeding program. In spite of this, many hybrids have been made and tested; and although most of these were discarded because of inferior quality, some hybrids have been retained to form the basis of the more intensive breeding program now under way (2).

The English have had a program of hybridization and selection in production since 1907 and are leaders in the field of hop breeding. English hybrids which E. S. Salmon has developed have higher preservative values than the richest hops imported by English brewers. In addition to the improvement of flavor and aroma qualities of English hops, hybridization has also increased yields (13).

Similar improvement by breeding may be expected in American hops. The varieties now used by American growers will be improved or supplanted by new ones produced by the breeder. Of course, this will come about only after continuous experimentation over a long period of time.

Economics

The 1949 hops crop in Washington, Oregon and California totaled 49,340,000 pounds which is 12% above the 1938–1947 average of 44,146,000 pounds. Under a marketing agreement and order regulating the handling of hops, the U.S.D.A. fixed the quantity of the 1949 crop which could be handled as hops or in the form of hops products, at 39,000,000 pounds. The balance of the crop was not marketed; in fact, a large part of it was not harvested.

TABLE III

U. S. EXPORTS OF HOPS 1941-42 TO 1949-50[4]

Months	1941-42	1942-43	1943-44	1944-45	1945-46	1946-47	1947-48	1948-49	1949-50
	1,000 #	*1,000 #*	*1,000 #*	*1,000 #*	*1,000 #*	*1,000 #*	*1,000 #*	*1,000 #*	*1,000 #*
Sept.-Feb.	7,441	5,295	3,488	6,030	8,816	8,757	9,382	9,001	7,825
March-Aug.	2,018	3,378	2,823	2,656	5,474	3,503	1,699	3,375	....
Total	9,459	8,673	6,311	8,686	14,290	12,260	11,081	12,376	....

Before World War II a substantial part of the U. S. hop crop was exported. During World War II, U. S. exports increased markedly. Areas formerly supplied by Czechoslovakia and Germany switched to the United States and have continued importing from the U. S. because of slow recovery of hop production in those former major exporting countries. In fact, 39,981 pounds of U. S. hops were exported to Germany and 372,290 pounds to Czechoslovakia in the period from September to February, 1949–50 (18).

Many breweries in the United States use small quantities of foreign hops for blending purposes. Despite such statements in the literature as " The market for American hops has been unnecessarily limited because many American brewmasters, being of German birth, believe that foreign hops are superior " (7), in only five of the past 50 years have imports equalled or exceeded exports. These years were immediately before repeal of the 18th Amendment, 1932–33, and in the period 1935–36 to 1938–39, when production and consumption of beer in the United States were rapidly increasing. In 45 out of the past 50 years, exports have far exceeded imports.

Advertising

A well-known beer brewed in New Orleans has recently become increasingly popular throughout Louisiana because someone in this brewery's advertising department began to tell beer drinkers that this particular beer not only is manufactured with the best malting barley and the purest water but that it also contains lupulin. All American beer contains lupulin, and this fact was undoubtedly known to the advertising man who also knew that there is a limited number of items used in the manufacture of beer which can be alluded to as being superior to those used by competitors. However, the use of lupulin had never been emphasized in advertising beer before. Among the colored population of New Orleans, the rumor circulated that this substance, lupulin, increases man's sexual powers considerably, and sales of this beer have increased substantially.

[4] From: U.S.D.A., For. Agr. Circ. FH 1-50, May 5, 1950.

[5] From: U.S.D.A., For. Agr. Cir. FH 1-50, May 5, 1950.

TABLE IV

U. S. IMPORTS OF HOPS BY COUNTRIES OF ORIGIN IN POUNDS[5]

Period	Czechoslovakia	Yugoslavia	Germany	Russia	Others	Total
1947-48	2,407,961	112,178	2,722,355	303,031	8,226	5,580,751
1948-49	1,509,225	133,863	1,936,769	....	320,095	3,899,952
1949-50 Sept.-Feb.	1,726,378	937,927	1,707,197	....	12,243	4,383,745

The advertising of hops north of the Mason-Dixon Line is as honest and straightforward as the advertising mentioned above. The disadvantages of using seeded hops have been indicated. The qualities of a beer brewed in Massachusetts enhanced by the use of seedless hops are extolled in singing commercials. As yet no rumors concerning the effect of seedless hops on human metabolism, such as the one involving lupulin, have come to the attention of the writer. The importance of seedless hops is rather lengthily discussed during broadcasts of baseball games. A singing commercial mentions that this beer is made with the finest seedless hops. This is followed by a scientific monologue in which the listener is asked if he ever bit into a grape seed; then he is reminded, in case he has forgotten, that the grape seed is bitter; then the high point of the commercial is presented. The listener is informed that hop seeds are just as bitter as grape seeds, but that he need not fear encountering bitterness of this nature in this certain beer, for this beer is made with seedless hops!

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Utilization Abstract

Castor Oil. About 350,000,000 pounds of castor beans are annually needed in the United States, most of which come from Brazil, 80% of the crop in that country being shipped to the U. S. In recent years domestic production has been increasing, and in 1952 about one-seventh of the foregoing needs will be furnished by farms in California, Arizona, Texas, Oklahoma and neighboring States. Development of domestic supplies has been greatly dependent on the successful breeding of varieties suitable to North American economic and edaphic conditions. Great progress in this direction has been made by the U. S. Department of Agriculture and the Baker Castor Oil Company of California.

Certain very specific qualities of castor oil products render them extremely valuable in a great variety of industrial uses, perhaps the most significant of which today is their lubricating merit at high temperatures in jet planes. (I. M. Colbeth, *Chemurgic Digest 11(1): 4. 1952*).

Breeding Winter Barley for Hardiness and Disease Resistance[1]

This crop, valuable for pasturage and feed grain, is largely confined to the southern and eastern States, and northward extension of its range is promised by the prospects of success in breeding cold-resistant varieties.

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Winter barley is a crop important in the development of a diversified agriculture in Missouri and other States in the winter barley area. Its importance is derived from the merits of the crop.

Winter barley can supply an abundant and nutritious pasturage as well as good yields of excellent feed grain. It fits well in rotations with other crops and is a particularly favorable companion crop for starting legumes and grasses. It makes thrifty use of soil fertility and is one of the most efficient cover crops for the control of soil erosion during fall and winter. It can profitably replace corn on uplands where continued use of a cultivated crop is leading to waste and ruin of our fertile soils. Used in a double-cropping system with lespedeza, it permits the production of mid-summer and fall pasture and of an early grain crop—valuable contributions in a livestock farming area like ours, as supplies of pasturage and grain feed are normally low in these seasons.

Before the fullest use of the winter barley crop will be realized, it needs to be made a safer crop for the farmer to grow. This can be accomplished by (*a*) use of good production practices, (*b*) liberal applications of fertilizer to the barley crop, and (*c*) improvement in the inherent hardiness and disease resistance of the varieties grown.

Production problems have long been studied, and practices by which winter barley may be grown in rotations with legumes and grasses have been described (7). Extensive use of fertilizers to supply the plants with nutrients deficient in the soil, an important factor in the safety of the barley crop, since it is less tolerant of nutrient deficiencies than many other cereals, is now becoming commonplace. But the breeding of improved winter barley varieties has not progressed as rapidly as has the breeding work in other cereals, or even in spring barley. It is the purpose of this paper to point out the possibilities of breeding improved varieties that will better withstand the rigors of our winters and escape the ravages of diseases common to the winter barley crop. Through this development the safety of the winter barley crop may be greatly increased and its area of production perhaps extended northward.

Need for Hardy Varieties

The production of winter barley in the United States is largely confined to the southern and eastern States, with scattered areas of production in Washington, Oregon, Idaho, Utah, Nebraska and Colorado. In the mild climate of California, the Southwest, and the gulf coast, spring type varieties of barley may be fall seeded without danger of winter injury. But as one proceeds

[1] Missouri College of Agriculture journal series number 1260.

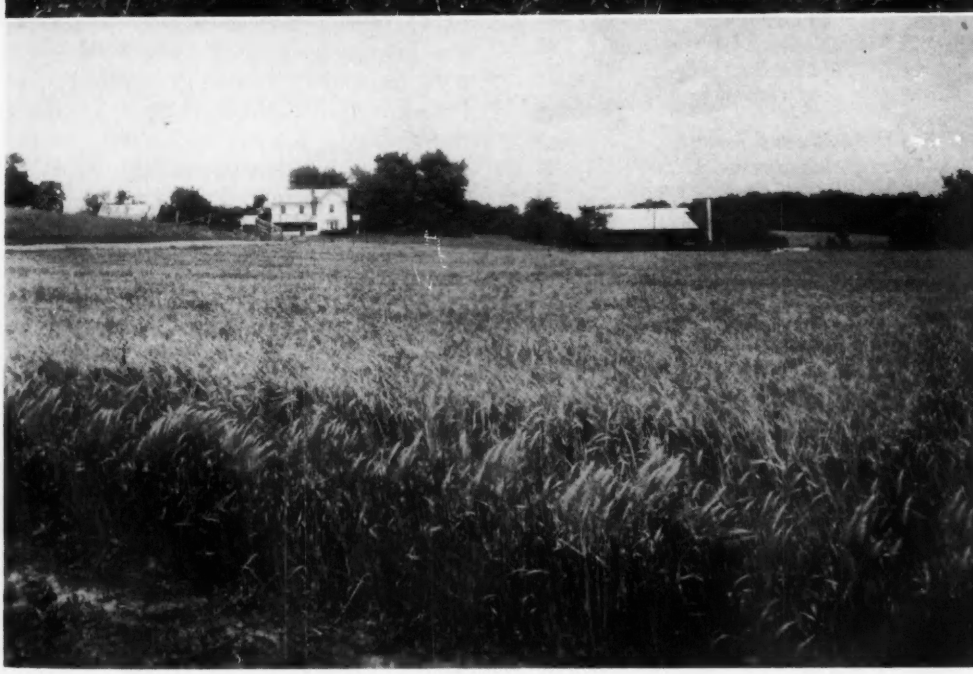

FIG. 1 (*Upper*). Soil erosion could scarcely occur in such a thick spreading growth as is found in this winter barley seeded at Columbia, Missouri, in early September. This crop is ready for a long period of fall grazing.

FIG. 2 (*Lower*). Winter barley is the earliest maturing feed grain crop. Its special value as a feed grain is found in its high yields, light draft on soil fertility, economy in production and high nutritive value.

northward in the winter barley area, increasing hardiness is needed. In Missouri only the most hardy winter type varieties now available can be safely grown, and even then losses necessitating abandonment frequently occur when cultivation of winter barley is attempted in the northern one-third of the State.

The need of increased hardiness here is illustrated in Table I by the average survival of seven varieties grown at Columbia, Missouri, in the uniform barley winter hardiness nursery continuously through the nine-year period 1942 to 1950. Some killing occurred in Reno and Kentucky 1, two of the most hardy rough-awned Tennessee winter type varieties every year. Missouri Early Beardless, the most hardy variety of the hooded type, and Wong, Smooth Awn 86 and Tennessee Winter (C.I. 6034), varieties intermediate in hardiness, were more severely injured. Trebi, a spring type variety, scarcely survived in even the mildest winters.

TABLE I

AVERAGE PERCENTAGE SURVIVAL OF WINTER BARLEY VARIETIES GROWN AT COLUMBIA, MO., IN THE UNIFORM BARLEY WINTER HARDINESS NURSERY, 1942 THROUGH 1950

C.I. No.*	Variety	Average percent survival
6561	Reno	92
6050	Kentucky 1	90
6051	Missouri Early Beardless	78
6728	Wong	68
6268	Smooth Awn 86	62
6034	Tennessee Winter	61
936	Trebi (spring type)	13

*C.I. Number refers to the accession number of the Division of Cereal Crops and Diseases, U. S. Department of Agriculture.

This winter injury to the barley at Columbia occurred both from direct killing by low temperature and from heaving. In Missouri temperature changes during winter may be rapid and extreme with protective snow cover uncertain. Alternate freezing and thawing of the heavy soils in late winter may also result in considerable heaving. Losses by this latter method of injury were quite severe in 1950. The exact cause of killing, whether from low temperature or heaving, is often difficult to identify, for plants with root systems injured by low temperature will be lifted out of the ground before spring. All of this emphasizes the need for improving the inherent hardiness of our varieties as a means of increasing the safety of the winter barley crop.

Breeding for Hardiness

How may the improvement in hardiness be achieved? Several means deserve immediate attention. First, introduction, from other areas of the world, of strains with superior hardiness offers definite possibilities. It was the introduction of Turkey Red wheat with its cold and drought resistance, first by a group of Mennonite emigrants from the plains of Russia, that made possible a stable wheat production in the Central Great Plains area of the United States. But the prospects of introducing a barley with those qualities are not so bright.

In the fall of 1942, 654 winter barley introductions from the United States Department of Agriculture world collection were planted at Columbia. These 654 strains came from several distinct geographic areas: Korea, China, Manchuria, the Caucasus and closely related areas, western Europe, the Mediterranean area, Ethiopia, Japan and India. They were grown in comparison with the rough-awned and hooded Tennessee Winter types most prevalent in the northern winter barley area of the United States. It may be noted from Table II that most of these introductions were inferior in hardiness to the best Tennessee Winter types. None was so hardy

as Reno, a local rough-awned Tennessee Winter type variety used as a check.

The rough-awned Tennessee Winter types, believed to have been introduced into the United States many years ago from the Balkans (1), are well acclimatized to northern winter barley areas of the United States. They are the most hardy sources of breeding material now available. While it is entirely probable that in their native habitat, indigenous strains exist which through natural selection over many years have attained a hardiness superior to that of the Tennessee Winter types, they have not yet been found by us.

A second method of improving hardiness is the crossing of varieties to obtain genetic recombinations with greater inherent hardiness, a procedure long used by the plant breeder. While the most direct procedure available for improving hardiness, positive results will come very slowly unless more hardy parent material is found. Greatest success will probably be attained by crossing extremely hardy types of different origin, thereby increasing the possibility of obtaining transgressive improvements. It is in such crosses that the introduced barley types described above may eventually prove most useful. But the possibility that complimentary genes may be available in relatively non-hardy, or even frost-resistant spring types, should not be overlooked. Finally, improvement by this method will be dependent upon the breeder's ability to isolate and identify accurately the segregates with genes for superior hardiness, however slight the improvement over existing types may be. This will require careful and persistent testing of selections from these crosses in areas where winter injury commonly occurs.

TABLE II

SURVIVAL OF WINTER TYPE BARLEYS AT COLUMBIA, MISSOURI, DURING THE WINTER OF 1943-1944

Variety source	Number of varieties with survival of					
	0 %	1-20 %	21-40 %	41-60 %	61-80 %	81-100 %
Local varieties:						
Rough-awned Tennessee winter	....	....	....	2	2	19
Hooded Tennessee winter	....	....	....	....	23	7
Introductions from:						
Korea	2	10	11	19	48	1
China-Manchuria	9	14	35	37	12	2
Caucasus area	24	16	52	80	34	....
Western Europe	39	3	3	3	11	....
Mediterranean area	32	14	4	3	1	....
Ethiopia	91	1	2	4	1	....
Japan	2	6	4	1	1	....
India	12	1	....	....	....	....

Obtaining better survival through disease resistance is a third and different approach to the problem. Various root-infecting diseases, most common in Missouri being spot blotch (caused by the organism *Helminthosporium sativum*), injure barley growing in the field in the fall. They hinder root development, lower the vigor of the plant, and may even kill part of the leaf tissue. The weakened plants succumb readily to the rigors of cold and to heaving. Also, barley leaf tissue covered in the fall with infections of mildew or leaf rust is easily killed by freezing temper-

atures. Smut-infected plants are winter-killed more readily than non-infected plants. Resistance to disease will not increase the inherent hardiness of barley strains, but it will reduce the winter injury which normally occurs to disease-ridden plants when epiphytotics of these diseases are present. Sources of resistance to most of these diseases are available, and incorporation of resistance genes into present hardy varieties offers a means of reducing the winter injury, even if it does not increase the inherent cold hardiness of the barley crop.

Studies by Gustafsson (3) and Gustafsson and MacKey (4) suggest a fourth, although yet unproven, possibility of obtaining strains superior in hardiness. These workers have obtained, by X-raying barley seeds, improvements in morphological and physiological characters, such as straw-stiffness, earliness, reduced height, brewing quality and grain weight. While no hardiness mutations have been reported, this possibility should not be overlooked if improvements in such complex agronomic characters as those reported above can be obtained by this method.

To observe that a slow, yet positive, advance in the development of hardier varieties is being made, one needs only to examine the reports of the U. S. Department of Agriculture cooperative winter hardiness nurseries since their establishment in 1938. Successively, C.I. 6050 Kentucky 1, C.I. 6561 Reno, C.I. 7523 Purdue 1101 Selection and C.I. 7580 Nebr. 412490 have led this nursery in survival percentage. The latter is a selection from a composite cross (5) and undoubtedly represents a transgressive improvement. Careful and persistent application of the methods outlined here should result in further advances.

Breeding for Disease Resistance

Turning to the breeding of disease-resistant varieties, we find a more plentiful and diverse supply of parent material than for the breeding of varieties with greater winter hardiness. In the spring barley areas of the United States, where improvement of the barley crop has been more vigorously pursued than in the winter barley area, sources of resistance to most of the major diseases have been identified. A number of spring varieties with resistance to one or more of these diseases are now in commercial use. But the use of spring varieties as sources of disease resistance will increase the difficulty of reaching the objective of greater winter hardiness, for few indeed will be the segregates from these spring × winter crosses that are as hardy as the winter parent. By an intensive backcross program many of these resistance genes could, no doubt, be transferred to the winter type varieties with a minimum loss of hardiness.

At the Missouri station we have looked for sources of disease resistance in the hardy winter types, for through use of these varieties it appeared that superior hardiness could be more easily retained and perhaps might even be increased. Our studies indicate that genes for resistance to the common diseases are present in many winter hardy varieties. The performance of individual strains have already been reported (6) and will not be repeated here. In the studies reported, resistance to the three smut diseases were identified through the use of artificial inoculation techniques, and observations on resistance to mildew (*Erysiphe graminis hordei*) and scald (*Rhynchosporium secalis*) were made from natural infections of these diseases in the field.

The number of varieties resistant to certain diseases in each of several important variety sources is reported in Table III. While some of the varieties reported here as resistant may, upon further study, be found to be susceptible to different races of the disease organisms, or when infected under different

environmental conditions, the results do point to certain specific sources of disease resistance in winter barleys which will be discussed briefly.

The rough awned Tennessee Winter type varieties, common in the northern winter barley area, are all very susceptible to the smut diseases and to mildew, but most of them have good resistance to scald. Addition of smut resistance to these hardy types is currently one of the major disease breeding problems in the northern winter barley area. The hooded Tennessee Winter type varieties were found to be one of the best sources of smut resistance. Many of these hooded varieties are resistant to the *nuda* loose smut, and several, in addition, are resistant to the *nigra* form of loose smut.

One strain, C.I. 6574 Hooded 16, is resistant to all three of the smut diseases. In studies by Cloninger (2), with a large number of collections of the *nuda* smut organism obtained from 12 States in the winter barley area, C.I. 7026 North Carolina 26 and certain other hooded strains were resistant to most if not all of these collections. His work indicates that this type of resistance should give adequate protection from the *nuda* loose smut now common in the winter barley area.

Many introduced winter barley varieties in the U. S. Department of Agriculture world collection, from Korea, China and Manchuria, and from the Caucasus area, are also resistant to local collections of the *nuda* loose smut. Many varieties of similar origin are resistant to the *nigra* loose smut, and a few are resistant to covered smut. Varieties from these areas have also been highly resistant to mildew at Columbia, but since mildew infections here are usually light, these varieties may not all prove resistant in the Gulf Coast or Coastal Plains areas where mildew infections on winter barley are more severe and race patterns are probably different. The susceptibility to scald of many of these introduced varieties, especially those from Korea, should not be overlooked if these varieties are to be used as parent material, or this disease might increase to major proportions in areas where it is now unimportant.

With these many sources of disease resistance already identified, attention should now be centered on the identification of specific genes for resistance in

TABLE III

NUMBER OF VARIETIES IN SEVERAL OF THE MAJOR VARIETY GROUPS RESISTANT TO CERTAIN DISEASES

	Number of varieties	Number varieties resistant to				
		Ustilago nuda	*Ustilago nigra*	*Ustilago hordei*	Mildew	Scald
Local varieties:						
Rough-Awned Tennessee Winter types	23	None	None	None	None	17
Hooded Tennessee types	30	22	11	1	1	1
Selections from composite crosses	5	1	None	None	None	None
Introduction from:						
Korea	48	11	19	7	30	None
China and Manchuria	28	6	15	4	15	2
Caucasus area	65	15	15	15	18	1
Western Europe	11	None	None	None	1	2

these varieties. This will necessitate that increased attention also be given to studies of specialization of these disease organisms and to the possible distribution of specific physiologic races of the diseases in the winter barley area. Other diseases also need to be studied. Spot blotch, caused by *Helminthosporium sativum,* frequently causes injury in the fall. While a few observations of resistance have been made at Columbia, they are too meager to discuss here. Other diseases of occasional importance are leaf rust, scab and stripe.

Reaching These Objectives

To reach the combined objectives of winter hardiness and disease resistance, careful selection of parent variety material must be made. The rough awned Tennessee winter types are our most hardy types. Their ecological adaptation to the northern winter barley area long has been established. Not only must they serve as the basis for any breeding program to improve winter hardiness, but they also offer the best sources of resistance to scald. The hooded Tennessee Winter types, like the rough awned types, are also ecologically well adapted to the northern winter barley area, though less hardy and less productive than the latter. But in selections from Missouri Early Beardless and North Carolina 26, we have some of the most winter hardy of the smut resistant varieties. Varieties from these two sources, it would appear, offer our best opportunity to combine winter hardiness and disease resistance, with the possible exception of mildew resistance. From crosses already made at the Missouri Agricultural Experiment Station between Missouri Early Beardless selections and several of the rough awned winter types, numerous strains,

AREAS OF BARLEY PRODUCTION IN THE UNITED STATES

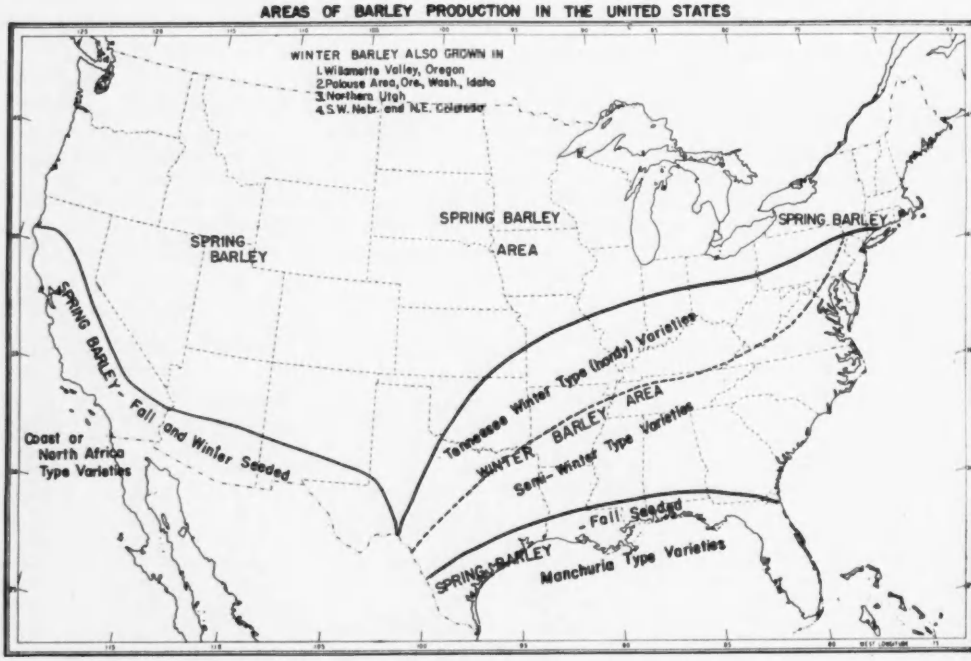

FIG. 3. Areas of barley production in the United States.[2]

[2] In making this chart, suggestions were received from Dr. G. A. Wiebe, Division Cereal Crops and Diseases, U. S. Department of Agriculture, Beltsville, Md.

FIG. 4 (*Upper*). Barley test plots at the Missouri Agricultural Experiment Station. On the left is Reno, a hardy rough-awned Tennessee Winter type; and in the center, Missouri Early Beardless, a hooded Tennessee Winter type variety. At the right an experimental selection is being compared with these standard varieties.

FIG. 5 (*Lower*). Non-hardy barleys are easily winterkilled at Columbia, as seen in the comparison above between two rows of a semi-winter type variety (left) and two rows of a hardy Tennessee Winter type variety (right), growing in the barley breeding nursery.

high yielding, with desirable agronomic qualities and with resistance to one or more of the common diseases have been obtained. One variety, Mo. B–400, from the cross Kentucky 5 × Missouri Early Beardless selection, has already been distributed, giving Missouri farmers their first opportunity to grow a hardy and productive variety with some smut and mildew resistance. While selections with good hardiness have been obtained, in no case has the hardiness of a selection thus far obtained from a cross between the rough-awned × hooded Tennessee types exceeded that of the rough-awned parent variety.

While the ecological adaptation of the introduced barley varieties to Missouri conditions is not well established, and none is so hardy as the best rough-awned Tennessee Winter type varieties, their diverse origin would suggest that they may have hardiness genes not found in the Tennessee Winter types. It is therefore possible that both hardiness and disease resistance could be contributed by these varieties, if they were used in crosses with locally adapted hardy varieties. These possibilities merit careful study.

One source of varieties, the composite crosses of Harlan and Martina (5), have been given little consideration here. While several varieties have been obtained from these crosses, with varying combinations of disease resistance most of these selections do not have the extreme hardiness necessary in the northern winter barley area. One exception is C.I. 7580 Nebraska 412490 which had the highest survival percentage in the U. S. Department of Agriculture uniform hardiness nurseries in 1949 and 1950, but which is very susceptible to the smut diseases.

The breeding problems discussed here will apply in general to the area where the hardy Tennessee Winter type varieties are now grown. Farther south, where the semi-winter types may be used, less emphasis needs to be placed on hardiness and perhaps more on disease resistance. Other qualities needed in winter barley varieties, but not discussed here, include better straw, resistance to shattering, earliness, forage production, high bushel-weight and withal high yield.

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Microbial Synthesis of Riboflavin[1]

This member of the vitamin-B complex is necessary in human diet to prevent soreness of mouth, lips and nose, and inflammation of the cornea. It is commercially produced from the fungi Ashbya gossypii *and* Eremothecium ashbyii, *and is used to enrich various foods and animal feedstuffs.*

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Peoria, Illinois

Most microorganisms are capable of synthesizing the various vitamins which make up the water-soluble vitamin B-complex. In certain instances this capacity for vitamin synthesis is of sufficient magnitude to justify the use of selected strains for industrial production of these vitamins. Processes based on the utilization of waste materials, such as distillery slops and sulfite waste liquors, have provided satisfactory and profitable outlets for materials which would otherwise constitute difficult and expensive disposal problems. The fermented liquors obtained through the action of microorganisms on mashes of this type may be concentrated for use in feedstuffs, or the individual vitamins may be extracted by appropriate techniques for use in pharmaceuticals, or to supply other markets for the pure vitamins.

Fermentation processes for the production of riboflavin (vitamin B_2, or G) have been highly successful and have attracted considerable attention. A number of fungi, under appropriate conditions, synthesize large amounts of this vitamin. However, at the present time only a limited number of these offer promise as industrial sources of riboflavin.

Synthesis of Riboflavin by Bacteria

Only three genera of bacteria appear to offer promise for the production of supplements rich in riboflavin. Of these, the genus *Clostridium* is most outstanding; the genera *Aerobacter* and *Azotobacter* are of considerably less importance.

Clostridium. Subsequent to the work of Warburg and Christian (157) who demonstrated that *Clostridium butyricum* contains riboflavin, Miner (170) demonstrated the feasibility of the use of selected clostridia for the production of riboflavin concentrates. He observed that members of the group which are employed industrially for the production of acetone and butanol synthesize considerable amounts of the vitamin under appropriate conditions. This discovery led to the successful utilization of distillery slops obtained in the neutral solvents fermentation (137). These observations were confirmed by the work of Yamasaki and Yositome (164–167, 172). Since that time a considerable literature has appeared covering many aspects of riboflavin production by these organisms.

Species of *Clostridium* which possess marked flavinogenic capacities are for

[1] Report of a study made under the Research and Marketing Act of 1946.

[2] Present address: Fermentation Division, U. S. Industrial Chemicals Co., Division of National Distiller's Products Corp., Baltimore, Md.

[3] One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, U. S. Department of Agriculture.

the most part those closely related to *C. acetobutylicum*, *C. roseum*, *C. propylbutylicum* and *C. felsineum*. Because of the industrial significance of certain of these organisms for neutral solvents production, many strains have been described, most of which synthesize riboflavin. The exact relationships of many of these so-called strains are not clear.

From the data available it appears that the clostridia are unable to synthesize more than limited amounts of the vitamin in chemically defined media (6, 146). Certain natural substrates, principally those employed as raw materials for the production of neutral solvents, have proved most satisfactory. The cereal grains, prepared as mashes of from 2 to 8% concentration, have served effectively as basic ingredients for the production of fermentation residues high in riboflavin and other vitamins. Concentrates containing as much 8000 μg. of riboflavin per gram of dry residue have been prepared from these materials (10). Ground whole grains, *i.e.*, rice, wheat, rye, oats, maize, millet, sorghum, corn and dehulled barley, have proved to by excellent substrata (10, 108, 164–167, 172, 173, 175, 177, 203–206). Rice bran and mixtures of rice, corn and barley have been utilized also (175, 205, 206). Other materials that have been suggested for successful production of riboflavin-rich residues include milk byproducts, such as whey (169, 172, 176, 184–186, 189–193, 210, 211); molasses (170, 202, 206) and potatoes (204). Polished rice, rice gluten, whole barley, panicum, sweet potato and cassava have been reported to give low vitamin yields (167, 204). Incorporation of certain of the last named materials with corn and brown rice, however, has led to moderate synthesis of riboflavin (175, 204).

Mashes for riboflavin fermentation may be supplemented with various carbohydrates: glucose, sucrose, dextrin, starch, or xylose. Added vitamins, such as biotin and *p*-aminobenzoic acid, have proved beneficial in special instances with materials like whey.

It has been repeatedly demonstrated that cations (iron, calcium, barium, lead, copper, nickel, cobalt, magnesium, zinc, manganese, tin, lithium, strontium, aluminum) and anions (thiosulfate, bisulfite, sulfite, pyrosulfite, hydrosulfite, iodide) markedly influence the course of riboflavin synthesis by the clostridia (60, 108, 129, 165, 166, 172, 173, 176, 177, 184–186, 189–193, 197, 203, 210, 211). Riboflavin synthesis appears to be delicately balanced in respect to the presence of these ions. In fact, their concentrations in the raw materials, the mashing water and the steam used for sterilization may be sufficient to result in negligible production of the vitamin or, conversely, increased yields. Table I lists the effective ranges of these ions (as salts) reported in the literature. In many cases, although riboflavin production may be greatly reduced, there is little or no effect upon the yield of neutral solvents. Control measures include cleaning of raw materials, careful selection of fermentation equipment, control of the purity of water employed and addition of materials which presumably tie up ions inhibiting flavinogenesis. These include 2,2′ bipyridine, potassium iodide, yeast, catalase and various sulfur-containing compounds (40, 60, 177, 183, 197).

The occasional overlapping of the beneficial and inhibitory ranges in Table I might be explained by the presence and close interrelationship of other ions. The patents of Rodgers, Pollard and Meade (176, 184–186, 189–193, 210, 211) effectively illustrate the need for balancing the ion content of certain mashes for optimal riboflavin production.

Table II, compiled from reported data, indicates the relative potentialities for production of riboflavin of a number of nutrient mashes commonly employed for

TABLE I

INFLUENCE OF INORGANIC IONS ON THE PRODUCTION OF RIBOFLAVIN BY ACETONE-BUTANOL-PRODUCING CLOSTRIDIA

Compound	Beneficial range %	Inhibitory range %
Calcium carbonate	1–3	....
" acetate	0.5	1–2
" lactate	0.5–1.0	2
" chloride	....	0.5
Barium carbonate	1	....
" acetate	0.5	....
" lactate	0.5–1.0	....
" chloride	....	0.5
" sulfite	0.02	....
Lead acetate	0.025–0.10	0.0003–0.3
Magnesium acetate	....	0.05
" lactate	....	0.05
" chloride	....	0.05
" sulfate	< 0.6	....
Zinc carbonate	....	1
" acetate	0.0003–0.003	0.025–0.3
" as sulfate	< 0.0003	....
Manganous sulfate	< 0.002	0.025–0.05
Cupric acetate	0.0003	0.003–0.03
Cuprous chloride	....	0.003–0.03
Iron (ferrous sulfate)	0.00001–0.001	< 0.00003, > 0.001
" (basic acetate)	....	0.0003–0.03
" (black)	....	0.0005–0.005
Cobalt acetate	....	0.0003–0.03
Sodium sulfite	0.014–0.043	....
" bisulfite	0.01	....
" thiosulfate	0.03	....
" hyposulfite	0.0005–0.003	0.01
Potassium sulfite	0.02	....
" pyrosulfite	0.02	....
" iodide	0.002	0.0005–0.01
Ammonium sulfite	0.02	....
" sulfate	0.0005–0.3	....
Aluminum acetate	trace	....
Ethyl sulfite	0.02	....

that purpose. Suitable preparation and use of inocula for the clostridial fermentations has been stressed (165, 193). Fermentations proceed for as long as 92 hours and are carried out at or near 37°.

Aerobacter. Selected species of the genus *Aerobacter* have been recommended for possible use in the production of fermentation residues high in vitamin content. Until 1943, however, only limited capabilities for synthesis of riboflavin had been attributed to members of the genus. Yields of less than 110 μg. of riboflavin per gram of fermented residue, and of less than 10 μg. per ml. of fermented liquor, had been reported for *A. aerogenes*, *A. cloacae* and *A. oxytocum* (15, 85, 103, 146, 148, 162).

The organisms were cultivated in synthetic or semi-synthetic media.

In 1943, Novak and co-workers (75, 188) demonstrated the feasibility of utilizing the foregoing species for increasing the vitamin B-complex content of stillage. They reported that the riboflavin content of stillage could be increased as much as fivefold by fermentation with *A. aerogenes* and as much as threefold with *A. cloacae; Aerobacter oxytocum* was found least suitable. They described a process for 100-gallon aerated fermentations conducted at 29° to 37° for 48 to 72 hours.

Production of limited amounts of riboflavin in the 2–3 butylene glycol fermentation with *A. aerogenes* has also been reported (209*a*).

Azotobacter. The genus *Azotobacter* has been demonstrated to synthesize limited quantities of riboflavin, with possibilities for industrial utilization. Three species, *A. agile, A. chroococcum* and *A. vinelandii*, have been studied. The principal advantage in employing this group of organisms for vitamin synthesis is that no exogenous source of nitrogen is necessary. Acceptable cell yields have been rapidly obtained in nitrogen-free media, and the absence of nitrogen further tends to limit contamination.

Employing mannitol or glucose as carbon sources in synthetic media, Jones and Greaves (41) and others (24, 103, 135) obtained only limited amounts of riboflavin. However, using sucrose as a carbon source in Burk's synthetic medium, Lee and Burris (57) have successfully conducted 300-liter aerated fermentations with *A. vinelandii*, yielding cell crops of as much as 10 to 11 pounds in 32 hours. These crops assayed as much as 350 μg. of riboflavin per gram of dry

TABLE II

EFFECT OF COMPOSITION OF MASH ON RIBOFLAVIN SYNTHESIS BY ACETONE-BUTANOL-PRODUCING CLOSTRIDIA

Mash	Maximum yield, μg. riboflavin per g. dried residue
Molasses, diluted	70
5% brown rice	4644
5% polished rice	1900
5% corn	3150
5% rice bran	160
2.5% rice bran - 9.5% molasses	36
Corn-brown rice (95%-5%) 5% mash	2935
" " " (90%-10%) 5% mash	2865
" " " (85%-15%) " "	3065
" " " (80%-20%) " "	3965
" " " (75%-25%) " "	4335
" " " (50%-50%) " "	4672
" " " (25%-75%) " "	2500
Corn-polished rice (75%-25%) 5% mashes	3286
" " " (50%-50%) " "	4319
Pearled barley-brown rice (75%-25%) 5% mash	1722
" " " " (50%-50%) " "	3163
" " " " (25%-75%) " "	3478
5% rice bran, 4.25% glucose	263
5% corn + zinc acetate	3430
Polished rice + sodium sulfite 5% mash	1550
Corn-polished rice (50%-50%) + sodium sulfite 5% mash	1980
" " " (50%-50%) + other sulfites 5% mash	2180
Whey, metallic ions adjusted	2800

cells. With molasses as a carbon source, slightly lesser amounts of the vitamin were obtained.

Other Genera of Bacteria. With minor exceptions, no other genera of bacteria have been suggested for use in industrial processes directed toward riboflavin synthesis. Myers and Weisberg (169) have obtained food products rich in vitamins, enzymes and lactic acid by subjecting whey and other milk byproducts to the action of lactobacilli or streptococci.

Of the remaining genera of bacteria which have been surveyed for flavinogenic capacity, none has been demonstrated to synthesize substantial amounts of the vitamin (Table III); cf. review by Peterson and Peterson (83). In only one instance has a yield greater than 10 μg. of riboflavin per ml. of fermented liquor been reported; Woiwood and Linggood (161) obtained 25 μg. of the vitamin per ml. with *Corynebacterium diphtheriae*.

Likewise very few bacteria have been reported to synthesize riboflavin in amounts greater than 100 μg. per gram of dried residue, or cells (Table III). Exceptions reported are *Escherichia coli,* 106 μg./g. (15); *Serratia marcescens,* 160 μg./g. (146); *Rhizobium trifolii,* 300 μg./g. (158); and *Pseudomonas fluorescens,* 310 μg./g. (146).

TABLE III

GENERA OF BACTERIA REPORTED TO SYNTHESIZE LOW YIELDS OF RIBOFLAVIN

Genus	References	Genus	References
	Maximum yields < 10 μg./ml. of fermented liquor		
Acetobacter	103, 149	*Micrococcus*	78, 103, 147, 148
Achromobacter	103, 147, 148	*Neisseria*	103
Aerobacillus	103	*Phytomonas*	67, 103
Alcaligenes	15, 103, 147, 148	*Propionibacterium*	148
Bacillus	15, 19, 103, 134, 147, 148	*Proteus*	15, 19, 103, 147, 148
Bacterium	103	*Pseudomonas*	103, 148
Chromobacterium	148	*Salmonella*	103
Corynebacterium	20, 22, 23, 103, 132, 151	*Sarcina*	147
		Serratia	103, 147, 148
Escherichia	15, 103, 147, 148	*Shigella*	25, 103
Flavobacterium	148	*Spirillum*	103
Klebsiella	147, 148	*Streptococcus*	134, 147
Lactobacillus	48, 103, 134	*Thiobacillus*	79
Leuconostoc	134	*Vibrio*	81
	Maximum yields < 100 μg./g. of dried residue, or cells		
Acetobacter	157	*Micrococcus*	128, 163
Alcaligenes	15	*Proteus*	15, 146, 163
Bacillus	15, 85, 163	*Pseudomonas*	162, 163
Escherichia	85, 128, 163	*Sarcina*	163
Flavobacterium	128	*Serratia*	162, 163
Lactobacillus	1, 128, 156, 157	*Streptococcus*	128

The information given in Table III was obtained for the most part in laboratory-scale experiments with expensive culture media not suitable for industrial production of the vitamin. As a rule, glucose was the sole carbon source tested. Length of fermentation varied from 24 hours to as much as 15 days, and cultures were incubated at temperatures varying from 25° to 40°. On the basis of the results it might be concluded that the bacteria represent an infertile field for

further investigative work on riboflavin synthesis. Nevertheless it might prove profitable to study this group under conditions more nearly simulating those employed in industry. The results of Novak and co-workers (75, 188), who obtained moderate yields of the vitamin in stillage with species of *Aerobacter* when earlier investigators had indicated these organisms to be poor producers of riboflavin, attest to this possibility.

Higher Bacteria. Various species of mycobacteria, including *M. tuberculosis* (human and bovine strains), *M. avium*, *M. berolinensis* and *M. smegmatis*, have been demonstrated to produce measurable amounts of riboflavin in synthetic media, *e.g.*, Long's, Sauton's, Lockemann's, Proskauer-Beck's, Kirchner's and modifications of these.

Of particular interest are the papers of Mayer and Rodbart (66) and Smith and Emmart (133) reporting studies on the mechanism of the synthesis of riboflavin by *M. smegmatis* and *M. tuberculosis*, respectively. These investigators found that glycerol was the most effective carbon source for riboflavin production, that certain inorganic ions markedly affected flavinogenesis, and that the nitrogen sources could be varied considerably with little effect on riboflavin production. The effects of including possible intermediates, such as alloxan and 4-amino-ribityl-xylidene, in media for the biosynthesis of the vitamin were investigated by the latter authors.

Lengthy incubation periods up to six weeks or more at 37° are required in most cases. Members of the genus *Mycobacterium* have been reported to synthesize as much as 57 μg. of the vitamin per ml. of fermented culture medium, and concentrates of cells have been produced which assay up to 36,000 μg./g. However, total cell yields are not outstanding (3, 8, 9, 66, 90, 103, 105, 133, 138), and the extended fermentation time would be unfavorable, quite aside from the pathogenic character of certain of these species.

Synthesis of Riboflavin by Yeasts

Practically all yeasts possess some flavinogenic capacity, as shown by their ability to grow in completely synthetic media lacking riboflavin, and by the presence of the vitamin in culture liquors where the organisms have grown (11, 14, 16, 17, 104). The flavinogenic capacity of yeasts has served primarily to enhance the value of selected species as food and feed yeasts. Those genera which are most productive include *Candida*, *Hansenula*, *Mycoderma*, *Mycotorula*, *Oidium*, *Rhodotorula*, *Saccharomyces* and *Torulopsis*. However, with the possible exception of various species of *Candida*, it does not appear that yields are of a magnitude sufficient to justify extraction of the pure vitamin from culture liquors.

Candida. In the genus *Candida*, three species, namely, *C. arborea*, *C. flareri* and *C. guilliermondia*, have been used for producing riboflavin on a semicommercial scale. A number of other species in the genus synthesize considerable amounts of the vitamin in synthetic media (14, 17, 38, 117). *C. arborea* has been studied principally in connection with its possibilities as a food yeast, the others for the production of concentrates high in riboflavin and other vitamins.

These species of *Candida* produce riboflavin in synthetic or semisynthetic media consisting of inorganic salts and trace elements; carbohydrate sources, such as molasses, sucrose, or glucose; nitrogen sources, such as $(NH_4)_2SO_4$, urea, asparagine, glycine, glutamic acid, sprouted seeds, hydrolyzed casein or other amino acid-containing materials; and the vitamin biotin. Molasses, treated to remove iron, has been reported to supply adequate amounts of biotin for the organisms.

As with the clostridia and mycobacteria, the inorganic ion content of mashes,

principally iron, has been found to markedly affect flavinogenesis. Tanner, Vojnovich and Van Lanen (143) and Tanner and Van Lanen (182) have employed 8-(OH)-quinoline or Nalcite MX or AX ion demineralizers to control the iron content of their media. They found optimal iron levels to range between 0.05 and 0.1 μg. of iron per ml. of culture liquor. Levine and co-workers (59) have confirmed these figures for optimal iron levels and report further that 1 μg./ml. levels of manganese, copper, zinc, tin, nickel or aluminum, added as salts, do not inhibit riboflavin synthesis.

Fermentations using species of *Candida* are conducted at or near 30°, with the initial pH of the media adjusted below 5.0. This aids somewhat in eliminating possible bacterial contamination. Fermentations are usually conducted under controlled aeration or agitation, or both, and may run as long as seven days. Peak yields are reported to be obtained between the fourth and seventh day of fermentation. Using these general methods, Agarwal and Singh and their coworkers (2, 131) conducted ten-liter fermentations with *C. arborea* in a mash composed of cane or beet molasses, $(NH_4)_2HPO_4$ and corn steep liquor solids. Total yeast crops up to 240 g., representing a 75% yield on the basis of the sugar fermented, were obtained. Yeast crops assayed up to 94 μg. of riboflavin per gram of dried material, depending upon the extent of aeration and agitation. It was found that increases in yeast cell yields generally were accompanied by decreases in riboflavin yields.

Candida flareri has been proposed for large-scale production of riboflavin concentrates by Tanner and co-workers (143, 182) and Levine and co-workers (59). With optimal iron concentrations in mashes composed of urea, asparagine and glucose, the former obtained up to 216 μg. of the vitamin per ml. This material when concentrated assayed up to 17,500 μg. of riboflavin per gram of dried material. Levine and co-workers obtained somewhat higher yields by using urea as the sole nitrogen source. As an added advantage, the process which they describe is best carried out with unsterilized media. Average yields of over 300 μg. of riboflavin per ml. and peak yields as high as 567 μg. per ml. were obtained in laboratory-scale fermentations. Representative spent liquors gave potencies as high as 28,400 μg./g. whole dry solids and 97,000 μg./g. of dried solubles. Total cell crops up to ten grams per liter of medium were obtained. Of 81 24-liter tank fermentations conducted with *C. flareri*, 28 gave yields in excess of 200 μg. of riboflavin per ml. However, with the larger fermentations the yeast was subject to variation or degeneration with subsequent loss of flavinogenic ability.

A somewhat similar range of yields has been obtained with *Candida guilliermondia* (11–13, 59, 112, 117, 143, 174, 182). Burkholder (11–13, 174) obtained yields up to 75 μg. of riboflavin per ml. of culture fluid and carried out extensive studies concerning the suitability of various carbon and nitrogen sources for flavinogenesis. Tanner et al. (143, 182), after adjusting the iron content of their media, obtained yields up to 157 μg. of riboflavin per ml. This material assayed as much as 18,500 μg. of riboflavin per gram of dried solids. With similar procedures, Levine and coworkers (59) obtained up to 175 μg. of the vitamin per ml. On concentration their culture fluids assayed up to 16,000 μg. of riboflavin per gram of dried solids, or 64,000 μg./g. of dried solubles. They found that with both *C. guilliermondia* and *C. flareri* it was possible to eliminate expensive asparagine and glycine from their mashes, provided media were not sterilized. In 24-liter tank fermentations riboflavin potencies obtained with *C. guilliermondia* were reported as

somewhat lower than those with *C. flareri*. However, semi-continuous fermentations could be carried out successfully for as long as 17 days with the former organism.

Rogosa (104) has indicated that *Mycotorula lactis* (*Candida lactis*) produces a limited amount of riboflavin in laboratory experiments. *M. lipolytica* has been employed in food yeast studies by Kurth (49) and Kurth and Cheldelin (50) with concomitant riboflavin synthesis to the extent of about 59 μg./g. of dry yeast. Total cell crops of 4.5 g./l. were reported in fermentations of supplemented wood sugar stillage mashes after 10 to 24 hours at 30°.

From the data it would seem that the low cell yields reported for species of *Candida*, when compared with *Ashbya* and *Eremothecium*, might constitute a disadvantage in the use of any process utilizing members of this genus for the production of riboflavin-rich concentrates. However, the ability to synthesize riboflavin in the amounts reported is noteworthy.

It is of interest that another member of this genus, *Candida krusei*, has been reported to synthesize an isomer of riboflavin (64). Riboflavin has been reported to inhibit the growth of this species. Such has been attributed to interference with glycolysis due to competition arising from resonance between the two similar types of molecules. Hedrick and Burke (38) have reported, however, a strain of this species capable of riboflavin synthesis.

Other Yeasts. Species of *Hansenula* have been reported to synthesize riboflavin in synthetic media which lacks this vitamin (16, 17, 38). *H. suaveolens* can be cultivated in wood sugar stillage media where it may synthesize up to 54 μg. of the vitamin per gram of dried yeast (49, 50). Fermentations are conducted in a mash composed of still waste liquors, $(NH_4)_2HPO_4$, and urea, with aeration for 18 to 24 hours at 30°. Total cell crops up to 4.6 g./l. of fermented medium are reported under those conditions.

Several investigators have stated that members of the genus *Mycoderma* are capable of riboflavin synthesis (14, 16, 17, 85).

Species of *Rhodotorula* have been reported to synthesize riboflavin (16, 38). Lundin (63), in Sweden, has described work directed toward the use of *R. gracilis* as a food yeast high in fat and protein. Riboflavin synthesis is limited, amounting to approximately 13 μg./g. of dried yeast. This yeast has been highly recommended as a food yeast, and suggestions for large-scale production have been made. Whey, molasses or wood and plant wastes have been recommended as possible substrata with fermentations complete in 50 hours.

Because of its importance in the distilling industry, the genus *Saccharomyces* has received considerable attention in relation to its ability to synthesize various growth factors, including riboflavin. Dried residues from alcoholic fermentations provide a valuable byproduct high in vitamins and other nutritional factors. In general, members of the genus synthesize riboflavin to the extent of 50 to 100 μg./g. of dry material. There is a considerable literature concerning the riboflavin content of bakers' and brewers' yeast (*S. cerevisiae*) and its synthesis of the vitamin (7, 14, 16, 26–31, 37, 38, 52, 58, 65, 74, 84–86, 125, 127, 140, 152–155, 157, 162, 163, 168, and others). Other species of this genus, in addition to *S. cerevisiae*, have been reported to synthesize riboflavin (14, 17, 104).

From an industrial standpoint a number of processes have been described for obtaining moderately high riboflavin-containing materials, employing species of *Saccharomyces*. These include use of *S. fragilis* to enhance the vitamin content of whey (169); improvements in

general processes for alcohol production whereby riboflavin content of yeast is increased slightly (**171**); fermentations employing spent yeasts in molasses and grain mashes, grain extracts or steep water (**178**); and the subjection of wet live brewers' yeast to low temperatures for periods up to 14 days to increase riboflavin content two- or threefold (**181**).

Singh et al. (**130, 131**) and Agarwal et al. (**2**) have studied the possibilities for production of *S. cerevisiae* as a food yeast in ten-liter fermentations. Total cell crops up to 134 grams were obtained in fermentations of cane or beet molasses, $(NH_4)_2HPO_4$ and corn steep liquor solids. The dried yeast crops gave potencies up to 50.4 μg. of riboflavin per gram. With aeration, riboflavin potencies were increased to as much as 108 μg./g. The factors affecting production of cells and vitamins were studied exhaustively.

The genus *Torulopsis* has received considerable attention because of its demonstrated value as a food yeast. A number of early reports concern its synthesis of riboflavin (**14, 16, 17, 36, 42, 85, 101, 104, 110, 111**). Although riboflavin yields approximate those obtained with other yeasts, they are not outstanding. Yields of cells have been obtained amounting to 50% based on the sugar fermented. Under special conditions the cell crops have assayed as high as 121 μg. of riboflavin per gram of dried yeast.

Torulopsis utilis has been the principal species studied. It is apparently adaptable to a variety of substrates for large-scale production. Processes have been described for production of *Torulopsis* food yeast in mashes containing molasses (**2, 62, 82, 131, 139, 140, 145**), fruit juices (**62, 139**), deoiled peanut meal (**45**), wood sugar solutions (**49, 50, 110, 111**) and whey (**169**). The use of mashes containing potatoes, straw, apple pomace, bracken or bananas as principal substrate materials has also been suggested (**82**). Most reports indicate that use of these mashes gives yeast crops with riboflavin potencies from 50 to 90 μg./g. of dried yeast.

Lewis (**61**) has reported that, as with species of *Clostridium, Mycobacterium* and *Candida*, the iron content of mashes markedly affects production of riboflavin with *Torulopsis utilis*. Cultures lacking iron or containing as much as 10 μg./ml. gave up to 121 μg. of riboflavin per gram dry yeast. Iron concentrations between these two extremes yielded smaller amounts of the vitamin.

Thaysen (**145**) and Peters (**82**) have described processes for large-scale production of *Torulopsis* food yeast in amounts up to 12 tons per day. They employ two strains, *T. utilis* var. *major*, a large-celled type, and *T. utilis* var. *thermophilia*, a form which grows preferably at 36°. Mashes are composed of dilute molasses, superphosphate and ammonia or ammonium sulfate with initial pH of 4.5. During the course of the fermentation additional amounts of ammonia and phosphorus are added. The final yeast crops have riboflavin potencies up to 100 μg./g.

Among other yeasts that synthesize moderate amounts of riboflavin and may be of some industrial concern, may be mentioned species of *Oidium*, which give potencies up to 55 μg./g. of dried yeast (**2, 131**), Kefir and Kuomys yeasts, and other lactose-fermenting types (**104, 169**).

Synthesis of Riboflavin by Other Fungi

With the exception of the two closely related yeast-like fungi, *Ashbya gossypii* and *Eremothecium ashbyii*, none of the higher fungi has revealed any ability to synthesize appreciable amounts of riboflavin. Such is clearly shown in Table IV, although available data are limited. Penicillin wastes have been

used as feed supplements; however, riboflavin potencies of these materials are low. Likewise it has been shown that certain aspergilli under special conditions synthesize limited amounts of the vitamin.

Ashbya. Prior to 1935, sporadic reports called attention to the production by *Ashbya gossypii* of a yellow pigment in aging cultures, *e.g.*, Farries and Bell (29) and Stelling-Dekker (136) in 1930 and 1931, respectively. The pigment was unmistakably identified as riboflavin by Guilliermond and co-workers (35) in 1935.

It remained for Wickerham and co-workers (159) to demonstrate that through strain selection and the use of proper media, considerable amounts of the vitamin could be synthesized by this organism. Subsequent to this, their selected strain, NRRL Y–1056, has been developed to a point where yields up to 1760 μg. of riboflavin per ml. of culture liquor have been obtained in laboratory fermentations with media containing peptone, corn steep liquor and glucose (92). Tanner, Pfeifer and co-workers (87, 142, 144, 187) described the development of a process for large-scale production of the vitamin with mashes consisting of animal stick liquor, tankage or meat scraps; corn steep liquor; and glucose, sucrose or maltose. This mash may be supplemented with lipids, such as corn oil, or with certain inorganic salts to improve yields.

Unlike most other industrially important riboflavin-synthesizing organisms, neither *Ashbya gossypii* nor *Eremothecium ashbyii* appears to be markedly affected by the presence of inorganic ions. This constitutes a distinct advantage for industrial processes.

With *A. gossypii* riboflavin production is the result of an aerobic submerged fermentation. The pH range of the fermentation lies between 4.5 and 8.0, and for this reason care must be taken to prevent bacterial contamination. In pilot-plant fermentations (150 to 300 gallons) yields of 500 to 600 μg. of riboflavin per ml. are readily obtained with use of an animal stick liquor, corn steep liquor, glucose mash. Fermentations proceed up to seven days at 28° to 30° with controlled aeration and agitation. Fermented mashes are ultimately concentrated by spray or drum drying to give concentrates ranging in potency from 25,000 to 30,000 μg./g. Total solids recovered in a 150-gallon fermentation average 25 pounds.

The literature concerning *A. gossypii* has been reviewed elsewhere (92), and details of the fermentation process have been described likewise (51, 87, 91, 142, 144, 187).

Eremothecium. *Eremothecium ashbyii* has received considerable attention,

TABLE IV

GENERA OF FUNGI REPORTED TO SYNTHESIZE RIBOFLAVIN *

Genus	References	Genus	References
Agaricus	18, 26a, 93	*Monascus*	42
Armillaria	70	*Penicillium*	18
Aspergillus	18, 30, 46, 89, 109	*Peziza*	18
Coprinus	162	*Pleurotus*	70
Cortinellus	70	*Verticillium*	42
Fusarium	18, 73	[fleshy ascomycete]	18
Irpex	47	[kefir mold]	126
Lactarius	160	[mold]	162

* Maximum yields < 35 μg./g. dried material.

since with it relatively high yields of riboflavin were obtained as early as 1936. The species, closely related to *Ashbya gossypii*, has been developed to a point where yields of the vitamin as high as 2480 μg./ml. have been reported from mashes suitable for large-scale production (212). It is probable that most of the available biologically produced riboflavin is obtained from processes employing this species, although the *A. gossypii* process is currently gaining considerable headway.

The riboflavin-synthesizing capacities of *E. ashbyii* were first noted by Guilliermond (33, 34) and by Guilliermond, Fontaine and Raffy (35). Since that time a considerable literature concerning this organism has appeared. Much of the information available is directly related to flavinogenic capacities. It includes fundamental studies concerning the effects of constituents of media on the synthesis of riboflavin (4, 5, 21, 34, 35, 42, 68, 69, 76, 77, 94, 97, 99, 100, 102, 113, 118, 123, 124); the characteristics of the vitamin as synthesized by *E. ashbyii* (32, 34, 35, 69, 76, 77, 95, 96, 98); the effects of aeration on riboflavin production (21, 94, 95, 99); the time required for production of riboflavin (97, 99, 100); the conditions affecting sporulatin of the organism (106, 107, 150); and the effects of various inhibiting agents, such as sulfonamides and dichloroflavin, on flavinogenesis (114–116, 119, 121, 122).

Apparently the organism is rather susceptible to variation. Substrains readily arise which possess little flavinogenic capacity. Similar phenomena apparently do not occur with equal frequency in *A. gossypii*. With *E. ashbyii* the tendency toward variation has presented problems in maintenance of stock cultures at peak flavinogenic capacity (4, 5, 97, 102, 120, 123, 150). Attempts to preserve flavinogenic capacity in strains by lyophilization or by preservation at 3° to 10° have been reported as unsuccessful (71, 72). In the writer's experience, *A. gossypii* can be conserved by lyophilization, but viabilities with this species are generally less than with many other microorganisms.

Eremothecium ashbyii is apparently capable of riboflavin synthesis in a greater variety of substrates than is *Ashbya gossypii*. This would appear to confirm the statements of Schopfer (113) that, although both species require biotin, thiamin and meso-inositol, *E. ashbyii* is more fastidious in that it requires certain other factors for growth. Basically *Ashbya* and *Eremothecium* possess unusual flavinogenic capacities. It is not improbable that enhanced riboflavin synthesis in both organisms represents their response to unfavorable conditions which divert riboflavin from its normal metabolic pathways; *E. ashbyii*, being more fastidious, might be adversely affected under a greater variety of conditions than *A. gossypii*. The versatility of *E. ashbyii* in this respect is attested by the numerous American and foreign patents (see below) covering processes for the production of riboflavin with this species.

According to Deseive (21), Pons Nemour (88) was probably granted the first patent covering the production of riboflavin with *E. ashbyii*. Yields as high as 80 μg. of riboflavin per ml. were claimed for a yeast extract–peptone medium, or a synthetic medium containing asparagine. Other substrata which have been recommended, primarily in the patent literature, include the following nitrogen sources: tankage (179, 180, 198, 213); fish meal (179, 180, 196, 198, 213); meat scraps (179, 198, 213); hide scraps (179, 198); peptone (71, 72, 88, 179, 196, 198, 207–209, 213, 214); egg albumen (179, 198, 213); malt extract (180, 195, 196, 209); various animal organs such as spleen (180, 196); dried blood and serum residues (180); liver

cake (196); yeast or yeast extract (71, 72, 198, 207, 209, 213, 214); casein, skim milk and other milk products (195, 196, 198, 207, 213); brain-heart infusion (207); lentils (212); corn, rice or wheat brans (199, 207); corn steep liquor (198, 207); corn gluten (198, 207, 213); corn or wheat germ (207, 208); soybean meal (198, 207, 213); wheat (198, 201, 213); beans and peas (198, 213); cottonseed, linseed and other oil meals (198, 213); stillage, ethyl and butyl slops, or distillers' solubles (71, 72, 196, 198, 199, 213); oat hulls or bone meal (199); and synthetic nitrogen sources (200).

Suitable carbohydrates employed in conjunction with these nitrogeneous sources include glucose, mannose, galactose, maltose, sucrose, lactose, raffinose and glycerol. Various lipid materials—corn oil, lecithin, olive oil, peanut oil, cocoa butter, butterfat, lard oil, cottonseed oil, coconut oil, cod liver oil, menhaden oil and various commercial shortenings and margarines—may also be incorporated in mashes with a suitable protein source and with or without added carbohydrate.

Of interest are the reports concerning the use of lipid materials in replacing carbohydrates for synthesis of riboflavin by *E. ashbyii* (179). Fermentations conducted in a peptone or egg albumen–inorganic salts–lipid mash gave yields of riboflavin slightly over 100 μg./ml. Corn oil was reported as particularly suitable for this purpose. It has been further demonstrated by Phelps (196) that riboflavin synthesis is increased considerably by the incorporation of lipid materials, such as butterfat, cream, corn oil or lard oil, in nutrient mashes. Yields of well over 1000 μg. of riboflavin per ml. were obtained when suitable concentrations of lipid materials supplemented the basal mashes. Addition of butterfat was particularly outstanding in its effects.

In several cases yields of riboflavin have been improved considerably by addition of extra sugar to fermenting cultures. Thus yields up to 1800 μg./ml. have been obtained in a mash consisting of peptone, neopeptone, wheat germ, inorganic salts and brown sugar by feeding additional sugar during the course of the fermentation (208). Moss and Klein (212) have obtained yields of riboflavin up to 2480 μg./ml. by feeding additional molasses to fermenting mashes composed of lentils, molasses and inorganic salts.

Of interest likewise is the patent of Tabenkin (200) which claims the production of as much as 700 μg. of riboflavin per ml. in a completely synthetic medium.

The fermentation process with *Eremothecium ashbyii* requires essentially the same conditions as the *Ashbya gossypii* process. Fermentations are conducted with controlled aeration and agitation, preferably at 27° to 28°. From information available it appears that the course of the fermentation requires slightly more time than the process with *A. gossypii*. Yields of riboflavin in dried concentrates have been reported with potencies as high as 20,000 μg./g. (71).

From other pertinent literature it appears that the tremendously high yields of riboflavin reported with both *A. gossypii* and *E. ashbyii* are probably obtained only in laboratory-scale fermentations. Fermentation industries look with favor on processes where lower yields are regularly obtained.

The potentialities of these most promising microorganisms for the industrial production of riboflavin are well shown in Table V which has been compiled from the data of Heuser (39) and from the writer's experience. The comparative economic value of dried fermentation residues of the selected microorganisms *Ashbya gossypii* and *Eremothecium ashbyii*, when compared with common natural sources of riboflavin, is obvious.

Penicillium. Use of penicillin fermentation residues as feed supplements,

TABLE V

BIOLOGICAL SOURCES OF RIBOFLAVIN

Substance	Riboflavin µg./pound
Dried skim milk	8,000–9,000
Dried buttermilk	9,000–14,000
Dried whey	10,000–12,000
Commercial liver meal	15,000–22,000
Dried brewers' yeast	15,000–18,000
Dried distillers' solubles	4,500–9,000
Distillers' dried grain with solubles	2,500–3,500
Alfalfa meal	6,000–8,000
Yellow corn	450
Wheat	450
Oats	450
Barley	450
Wheat bran	900
Wheat middlings or shorts	900
Soybean oil meal expeller	1,800
Corn gluten meal	900
Cottonseed meal	300
Peanut meal	1,200
Meat scrap	2,700
Menhaden fish meal	2,700
Sardine fish meal	3,200
Butyl and ethyl alcohol fermentation residues (*Clostridium*)	14,000–114,000
Ashbya gossypii or *Eremothecium ashbyii* fermentation residues	11,340,000*

*Writer's calculation, assuming average yields of 25,000 µg. riboflavin per gram of dried fermented mash.

based to a certain extent upon their vitamin content, has been proposed by Tanner and co-workers (141, 194). While relatively small quantities of riboflavin are present in such residues, concentration to the dry state increases the amounts of various vitamins, including riboflavin, to a point where their usefulness is unquestioned.

Aspergillus. Various aspergilli have been shown to synthesize riboflavin (cf. Table IV). Of particular interest are the reports concerning such synthesis by *Aspergillus niger* (18, 43, 44, 46, 53–56, 85). While synthesis of the vitamin is not outstanding in this species, it has been demonstrated that addition of mercuric or magnesium salts to synthetic media in which the organism is growing stimulates riboflavin synthesis. With these added salts the organism is capable of producing as much as seven times the amount normally synthesized. Such phenomena might be industrially significant in the disposal of fermentation residues from processes based upon the use of this species.

Miscellaneous Fungi. Peltier and Borchers (80) have approached the problem of flavinogenesis from a practical standpoint in surveying members of the genera *Alternaria, Fusarium, Hormodendrum, Rhizopus* or *Mucor*, and *Trichoderma* for their ability to produce riboflavin in a wheat bran mash. Species of *Aspergillus* and *Penicillium* were also included in the study. None of the isolates tested showed exceptional flavinogenic abilities, maximum riboflavin production approximately only 20 µg./g. of mash in most instances. Species of *Aspergillus* were found to be the most productive, giving yields up to 58 µg. of riboflavin per gram of dried mash. Species of *Fusarium* were also found to synthesize considerable riboflavin.

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Summary

Many microorganisms produce riboflavin in excess of their own requirements. The number of species which produce a sufficient excess to be of commercial interest is limited. Among the bacteria, species of *Clostridium* are outstanding, whereas species of *Aerobacter* and *Azotobacter* produce smaller but significant amounts. Of the yeasts, species of *Candida* show the greatest

flavinogenic capacities, whereas other yeasts, such as *Saccharomyces* and *Torulopsis*, produce sufficient riboflavin to enhance the nutritive value of cells produced for food and feed purposes. Of the fungi, the two yeast-like forms, *Ashbya gossypii* and *Eremothecium ashbyii*, are particularly outstanding and are capable of riboflavin synthesis far in excess of any other known micro-organisms. Realization of maximum riboflavin synthesis is dependent upon careful strain selection, use of suitable substrata and establishment of optimal fermentation conditions.

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BOOK REVIEWS

The Drug Plants of Illinois. L. R. Tehon. 135 pages; illus. Illinois Natural History Survey, Circ. 44. 1951.

Of the approximately 900 plant species used directly or as the sources of products in the American drug trade, about 350 of them grow as native, naturalized or cultivated plants somewhere in the United States, nearly 300 of them in Illinois. Varying amounts of these plants are collected every year and enter the trade through local buyers and such principal markets as those of St. Louis, Mo.; Asheville, N. C., and Marion, Va. While Illinois is not at present one of the major contributors to this industry, there are, however, significant amounts of crude drugs collected in various parts, particularly the southern part, of the State. "There is opportunity for residents of the State to engage more actively than they do now in the collection of crude drugs and, thereby, to increase their incomes by small to large amounts. It is the purpose of this publication to encourage the use of this natural resource by furnishing instructions for collecting, drying, packing, and marketing crude drugs and by listing, describing, and picturing those kinds of plants which are demanded by the trade". In offering this information, nearly 300 kinds of plants are pictured in excellent drawings, with brief descriptions and notes on their uses.

The Molds and Man. Clyde M. Christensen. viii + 244 pages. Univ. of Minnesota Press. 1951. $4.

Written for the layman and the beginner in a study of mycology, this volume contains, in addition to chapters on the biology of fungi, others on their economic significance, not only as agents of destruction but also as industrially exploited plants. Such utilization began with the Orientals more than 2,000 years ago in the manufacture of soy sauce, saki and cheese-like foods from soybeans and rice. Today it includes usage as food in the manufacture of cheeses and as cultivated mushrooms, and production of acids, drugs and enzymes. Each of these industrially valuable products obtained through modern utilization of molds is briefly discussed.

Flowering Trees of the Caribbean. xii + 125 pages. Rinehart & Co. 1951. $10.

This volume is primarily a work of art, for it is a collection of 30 magnificent paintings of Caribbean tree flowers by Bernard and Harriet Pertchik, excellently reproduced and accompanied by delightful accounts of the trees. A few of the trees represented have economic value, particularly in their wood, the most important of which is lignum vitae, *Guaiacum officinale*.

As early as the sixteenth century, in the manor houses of the English nobility, a prized item was a wassail bowl fashioned of lignum vitae from English colonies in the West Indies, and for 200 years after the Spanish first exploited the tree in South America, valuable medicinal qualities were attributed to its wood, bark, gum, fruit and flowers. Today some natives of Trinidad and Tobago use the resin of the tree as a local stimulant, especially for gout and rheumatism, but modern esteem of the tree is based upon its exceedingly durable, brownish-green heartwood—one of the heaviest if not the heaviest of all commercial woods. Its qualities place it in demand for manufacture into bowling balls, mortars and pestles, pulleys and mallet heads, but most distinctive is its great value, because of its self-lubricating nature, as the only successful natural material for propeller shaft bushings in steamships.

Potter's Cyclopaedia of Botanical Drugs and Preparations. R. C. Wren, revised by R. W. Wren. 6th ed. xlvi + 415 pages; illus. Potter and Clarke, Ltd., 60 Artillery Lane, London, E, England. 1950.

When a scientific reference work, first published in 1907, goes through six editions, it must certainly have great merit, and for that reason attention is here directed, though two

years late, to the latest edition of this well known pocket-size cyclopaedia. The original aim of this work was to " supply on a small compass the Common and Botanical title of every herb in general use, together with its synonyms, action, preparations and doses ", and fulfillment of this aim has been brought up to date in this edition with reference to the British Pharmacopoeia, 1948, the British Pharmaceutical Codex, 1949, and the United States Pharmacopoeia, XIII. Over 800 kinds of drug plants from " abscess root " through " zedoary " are alphabetically described, accompanied by several hundred drawings of them and several colored plates.

Medical Botany. Alexander Nelson. xii + 544 pages; illus. E. & S. Livingstone, Ltd., 16 Teviot Place, Edinburgh, Scotland. 1951.

This book is not, as the title might lead one to believe, limited to medicinal uses of plant drugs. Instead, it is much more comprehensive, and its scope is suggested in its sub-title: A hand-book for medical men and all who are concerned in the use of plants: nutritionists, dieticians, pharmacists and veterinarians. As such it contains chapters on the mineral and vitamin content of vegetable foods, and on their storage, processing and cooking, as well as detailed chapters on cereal grains, pulses, oil-seeds and nuts, leaf, stem and root vegetables, and on foodstuffs obtained from non-flowering plants. Over 370 pages are devoted to these topics, and the next 100 pages are concerned with vegetable drugs, poisons, stimulants and other plant products of pharmaceutical interest. Finally, there is a chapter on plants, other than bacteria, as positive causes of disease.

Plants for Man. Robert W. Schery. viii + 564 pages; illus. Prentice-Hall, Inc. 1952.

Perhaps the present reviewer is prejudiced because of his particular interest in the broad aspects of economic botany and of plant utilization, but it is especially pleasing to him to note the publication of this beautifully illustrated and excellently written textbook on man's uses of plants. Other volumes reviewed in these pages in past issues may, in the opinions of many, be greater contributions to botanical literature because they are more limited in scope and therefore more informative on particular topics for the specialist, but here is a noteworthy contribution to awaken the student and appreciative reader to the intimate relationship between modern industrial man and the vegetable world that sustains him.

Numerous maps from the U. S. Department of Agriculture, Office of Foreign Agricultural Relations, show the world production of many economically important crops, and hundreds of photographs, original or reprinted from several sources, contribute enormously, along with its attractive modern format, toward making this volume so praiseworthy. Perhaps most impressive, however, by way of illustrations is the reproduction of numerous exhibits and paintings from the Chicago Natural History Museum, depicting the native harvesting, processing or utilization of plants in various parts of the world. In addition, there are flow charts and drawings, and the 400 or so pictures which thus adorn the book make it one of the best illustrated volumes of recent years on economically important plants.

Pictures alone, however, do not make Dr. Schery's book praiseworthy; were it not for the well written text, it would not be so commendable, for the text, in addition to being authoritative so far as any text on so enormous a subject can be, has a delightful readability about it that pleasingly departs from the uninspiring nature of so much scientific writing. Furthermore, the text is not limited to mere descriptions of plants and to accounts of them in this, that and some other product. Instead, by brief discussions of the many industries, always in addition to descriptions of the plants and of their harvesting and processing, it conveys well rounded understanding of their relative import and of the bearing which certain other fields of modern technology may have upon them.

After two brief introductory chapters, 167 pages are devoted to products derived from plant cell walls, and make up chapters on the forest resources and uses of the world, on lumber, paper pulp and fibers. The next 164 pages cover cell exudates and extractions, *i.e.*, latex, pectins, gums, resins, oleoresins, tannins, dyes, essential oils, medicinals, insecticides, herbicides, tobacco, nonessential oils, fats, waxes, sugars and starches.

Food and beverage plants cover 180 pages, and a short concluding chapter considers microorganisms, mushrooms, hayfever plants and a few other miscellanea. Each of these topics is admirably discussed, not in a comprehensive manner for the specialist or even to serve as a reference work on the useful plants of the world, but rather in a well integrated text for classes and for general cultural reading.

The author, editor and publishers of this volume have certainly made a valuable contribution to recent botanical literature. It is hoped that publication of the book not only indicates a widening appreciation of plant utilization in academic circles but also that it will serve to increase that interest and to reveal to students not only the marvelous relationship that already exists between man and the plants which he has learned to use, but also the possibilities for still greater utilization of our replenishable natural resources.

Economic Botany—A Textbook of Useful Plants and Plant Products. Albert F. Hill. xii + 560 pages; illus.; sec. ed. McGraw-Hill Book Company. 1952.

In 1937 the first edition of this excellent work was published for the prime purpose of providing a textbook in the field of botany that would emphasize the cultural and human relations aspects of plant life for students not intending, or at least not yet having any desire, to pursue botany as a pure science. Plants and plant products at that time, and for generations before, had played as important a role in furnishing man with his necessities and his luxuries as they do today, but little cultural value was attached to acquiring academic information in the field. It was a mark of progress, therefore, when that first edition came from one of the great botanical departments in America, that of Harvard University, and thus, as it were, gave a stamp of approval to teaching botany as an applied as well as a pure science.

Since then, as a result of the European war and concomitant advances in various fields of science, as well as the war-inspired desire for America to become free of foreign sources of raw plant material, much greater interest in industrial circles has developed in plant utilization. A measure of this growth lies in the 140 more species of plants discussed in this new edition. Some of those additions might have been included in the first edition and do not necessarily represent plants that have suddenly come to the fore; most of them, however, do represent plants with newly acquired or greatly increased economic value. As such they are indicative of man's constant search for new raw materials and of his ingenuity in finding them.

Among the lower plants these new arrivals on the stage of industrial significance have been (*a*) certain red algae in the coastal waters of North America which have served as sources of agar formerly produced exclusively in Japan; (*b*) brown algae in the same waters that are now furnishing valuable extractives; (*c*) bacteria important in industrial fermentations; and (*d*), perhaps most important for man's actual welfare, the fungi that furnish antibiotics of constantly increasing importance in medicine. Among the higher plants, none of them has enjoyed the sudden fame acquired by the fungi in combatting some of man's diseases, but the latent possibilities of increasing our sources of fibers, tannins, medicinals, oils and dozens of other needed products are intriguing. Surely an appreciation of these possibilities should be a part of every educated man's background, and in providing this revised edition, the author and publishers have rendered a distinct educational service.

It so happens that the present reviewer, in his capacity as editor of the periodical in which this review is now appearing, has perhaps relied upon Dr. Hill's book more than any other single volume in verifying plant names and checking other bits of information. This reliance has developed primarily because of the remarkably wide coverage given in the first edition to the entire field of plant utilization, a feature which is now all the more important in view of the additional 140 species considered. Such wide coverage, under the economic exigencies of publication, could be made only at the sacrifice of some other feature, and this should be borne in mind by those who would criticise the book because of its scanty information on many particular topics.